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LECTURES ON BLOOD SUGAR.[*]

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LECTURE I.

*(Chairman. SIR B N SEAL, Vice-Chancellor,
The University of Mysore)*

MR VICE-CHANCELLOR, LADIES AND GENTLEMEN,

I deem it a very great pleasure and privilege indeed to have been invited by the University of Mysore to deliver this series of lectures on Blood Sugar in the Medical College at Bangalore, and I am very grateful to you, Mr. Vice-Chancellor, for the very complimentary manner in which you have spoken of me I cannot adequately express my thanks for the honour you have done me. The privilege of addressing you puts me under a heavy load of responsibility. I am only too conscious

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[*] Delivered at the University Medical College, Bangalore, Mysore University, on 16th, 18th and 20th September 1929.

of my own shortcomings When I received the letter from Dr B K Narayan Rao, Principal of the College, conveying the invitation of the University, I was glad to accept it, chiefly for the reason, that it gave me an opportunity to see a sister institution A liaison between the various Indian Universities is of the highest importance at the present moment, and no better method of bringing it about could be conceived than that adopted by you I therefore come in your midst as a student with a desire to learn, and I wish to express my sincerest thanks to the authorities concerned for offering me this splendid opportunity of doing so

The subject of Blood Sugar, with which I propose to deal, is of great interest in view of the prevalence of Glycosuria in India. I have divided it into three lectures. In the first I shall discuss mainly the normal concentration of sugar in the blood, in the second the variations in the amount of Blood Sugar and the Sugar Tolerance Test, and in the third, the application of these to the problem of Diabetes with special reference to India

I. The Food.

It is a characteristic feature of all forms of living things, that they are continuously and spontaneously undergoing change. On the one hand, the living substance is constantly breaking down, and on the other it is building itself anew with the help of food substance it takes in These processes of Ketabolism and Anabolism are taking place simultaneously and constitute the phenomenon of Metabolism, which is the fundamental fact of life

Food, therefore, is necessary for the maintenance of life. It is also indispensable for growth. Both plants and animals need it The manner of obtaining nutriment in the two cases, however, differs. Sugar is a form of food material, which is required by both, and for this reason it is widely distributed in the animal and vegetable kingdoms.

The plants derive their food material from the air and the soil. The CO_2 of the atmospheric air finds its way into the tissues of the green leaf through small apertures, known as stomata. These communicate with intercellular spaces by means of small channels. From there it passes into the cells containing Chlorophyll, the green colouring matter of plants. The water at the same time is absorbed by the roots from the soil, and makes its way up to the leaves with the ascending sap. The Chlorophyll of the green plants in the presence of sunlight builds up sugar from CO_2 and water, and sets free a certain amount of oxygen. A carbohydrate thus formed serves as food for the plant. The sugar in solution slowly passes down the veins of the leaf and the leaf-stalk into the main part of the plant During day-time more sugar is formed than can be transported by this slow process, and the result is that the sugar in the sap becomes more concentrated When the sap contains more than a certain percentage (0.5 per cent), the excess is converted into insoluble starch, which exists as small granules When the plant is removed to darkness these granules diminish in number, and may disappear As the new formation of sugar ceases, the amount in the sap tends to drop, and the starch is reconverted into sugar in order to keep up the supply. Thus sugar formed by Chlorophyll may be immediately used up by the plant when it is rapidly growing, or it may be stored in the form of starch, as food reserve for the future For instance, carrots and turnips store up grape sugar, while cane sugar is stored by sugarcane and beetroot, and starch by potatoes and rice

The interesting point is, that in the plant sugar is built up from CO_2 and H_2O in the presence of sunlight But the living matter of plants like that of animals also breathes, which means that it absorbs oxygen and gives off CO_2 during the whole of its life time, a process which takes place both in sunlight and in darkness. It breathes out CO_2 which it wants back as food, and it breathes in oxygen which it excretes as waste product of its food.

The Chlorophyll, which takes such a prominent part in the metabolism of the green plant is probably the most interesting substance in the universe According to the late Sir E Ray Lankester, " this action of Chlorophyll is the critical step in the interaction of chemical elements on earth's surface, by which life is at present determined. Were there no assimilation of carbon from carbonic acid to form sugar or starch by green plants, the whole fabric of the living world would tumble to the ground—in truth becomes mineralized All living matter breaks down, within a short space of hours or days to the resting or mineral condition of carbonic acid and ammonia (or nitrates). Were the building up process, the raising of higher potentiality not necessarily performed by green plants—a power which Chlorophyll and Chlorophyll alone confers on them—all carbon must pass from the reach of the organic world, and living matter come to an abrupt end "

The food of the animals consists of more complex substances. But they are ultimately dependent on plants for this purpose Carnivorous animals live on herbivorous ones, which live on plants. Thus all animals live on food-stuffs which the plants have built up It would not be an exaggeration to say, that Chlorophyll of the plant is the prime factor responsible for the existence of the entire living world

The animals thus derive their supply of carbohydrate from the vegetable kingdom The animal body is not able to synthesise this product from CO_2 and H_2O as the plants do with the aid of Chlorophyll and sunlight. In this respect, animals differ sharply from plants.

The carbohydrates are eaten by animals, and are finally broken up by them into CO_2 and H_2O and returned in that form to the atmospheric air Sugar, thus, is widely distributed in both the vegetable and animal kingdoms, and takes an important part in their metabolic processes.

Apart from carbohydrates, the animal body needs proteins, fats, salts, water and vitamines

The proteins, which contain Nitrogen in the proportion of about 16 per cent, are necessary for the building up of new tissues and for repairing tissue waste Carbohydrates, fats and to a certain extent proteins act as source of energy. Water is necessary to promote the solution of substances during absorption, metabolism, excretion, etc., while the salts and vitamines, act as general regulators of body processes, growth and protection of body against disease

The animal body may be regarded as a machine which converts the potential energy of food into the kinetic energy of muscular work and heat.

The daily output of energy of a man in the form of muscular work and heat is about 3,000 large calories It is less when a person leads sedentary life and is reduced to a minimum during complete rest in bed On the other hand, physical work may increase the daily expenditure from 4,000 to 5,000 calories or even more Apart from this, there is basal heat production or basal metabolism, which represents energy expended when the body is in a state of metabolic rest, unaffected by influences of diet and muscular work, which amounts to about 1,600 to 1,700 calories per day in adult men This is equivalent to about 39 to 40 calories per hour per square metre of body surface area. In women the figure is slightly lower In order to meet the energy requirement, the average man doing ordinary amount of work needs food of the caloric value of about 3,000 to 3,500 calories. Reckoning that 1 grm. of protein is equal to 4.1 calories, 1 grm. fat 9 3 calories. and 1 grm. carbohydrate 4 1 calories, the average diet should contain the following proportions of different food-stuffs —

	Calories.
Protein 100 grms. × 4.1	410
Fat 100 grms × 9 3	930
Carbohydrates 500 grms. × 4 1	2,050
Total	3,090

The bulk of the ordinary diet of human beings, especially in the tropical and sub-tropical countries, consists largely of various carbohydrates. All the starches and sugars of the foods, about 60 per cent of the protein amino-acids, and about 10 per cent of the fat, are converted into glucose in the course of metabolism Glucose is ultimately oxidized to CO_2 and water and furnishes the greater part of the energy which is manifested in the shape of muscular work and production of heat. The metabolism of glucose thus represents one of the most important reactions taking place in the animal body

II. History of Carbohydrate Food.

I will now trace briefly the history of carbohydrate food in the animal body.

A. DIGESTION.

All the digestable carbohydrate taken in with the food is converted by digestive agencies into monosaccharides, glucose and lævulose, and in this form it is absorbed into the blood of the portal system. Several enzymes play a part to bring about resolution of this carbohydrate material :—

1 *Ptyalin of Saliva.*—It is a diastatic enzyme In some animals it is secreted in an inactive or zymogen form When poured into the mouth, it comes in contact with the mucous membrane, and is then converted into active ptyalin by an organic kinase, *Orokinase,* secreted by small buccal glands in the mucous membrane of the cheek and lips.

It is not a powerful enzyme It acts on boiled starch, namely, starch which is in a free state, and not surrounded by cellulose envelope On this also ptyalin displays little of its activity during the time the food is in the mouth On raw unboiled starch with its cellulose envelope intact, its activity is negligible.

After the food is swallowed and becomes deposited in the fundus of the stomach, the action of ptyalin continues for some time. With the secretion of hydrochloric acid by the gastric mucous membrane, the slight rise in Hydrogen-ion concentration which results, assists the action of ptyalin on starch, but when this acid is present in a free state above a certain concentration the diastatic action of saliva is inhibited and finally stopped. The action of this enzyme is optimum in a neutral or slightly acid medium. The duration of salivary digestion in the stomach is 20 to 40 minutes, but it may be prolonged for an hour or more if the animal remains quiet after the meal, so that the mass of food is not rapidly broken up by bodily movements The products of ptyalin digestion are dextrin and maltose.

2. *The Gastric Juice* has no action on starch By virtue of the hydrochloride acid it contains, it to a certain extent inverts sucrose (cane sugar) into glucose and fructose. This action is frequently assisted by the inverting enzymes contained in the vegetable food swallowed

3. *Amylopsin of Pancreatic Juice.*—Its action, though similar to that of ptyalin, is very much stronger It causes hydrolysis of starch quickly with the production of maltose and achroodextrin It also acts on unboiled starch.

4 *Inverting Enzymes in Succus Entericus* —These enzymes convert disaccharides into monosaccharides This power the succus owes to three enzymes :—

(*A*) *Invertase* or sucrase converts cane sugar into glucose and lævulose (fructose)

(*B*) *Maltase* converts maltose into two molecules of glucose.

(*C*) *Lactase* converts lactose into glucose and galactose Lactase is most abundant in young animals at that period of life, when lactose is an important constituent of dietary Animals whose food does not contain one or the other of these sugars, the corresponding inverting enzyme is absent from succus entericus Herbivorous animals, for example, do not take any lactose in their food. Their succus entericus, therefore, does not contain any *Lactase*, although it is present in that of the young animals while still suckling

5 *Intestinal Bacteria.*—A certain amount of carbohydrate is attacked by intestinal bacteria They split the Monosaccharides into lower fatty acids, Acetic Acid, Lactic Acid, Bytyric Acid, Succinic Acid, and gases such as Methane, CO_2 and Hydrogen, also alcohol This is an obviously *destructive process*

Besides this, the bacteria perform a useful function in the digestion of carbohydrates, as certain strains of them digest *cellulose*, for which no special enzyme exists. Bacterial digestion is consequently helpful in herbivorous animals. It takes place in the cæcum, which is enormously developed for this purpose In carnivorous animals, the small intestine is relatively shorter than in the herbivorous Thus, in the cat it is three times the length of the body, while in the goat and sheep it may be nearly 30 times the length of the body. The reason for the great size of the cæcum and small intestine in the herbivorous animals is that practically the whole digestion of cellulose takes place in this part of the gut.

This digestion does not depend on any enzyme secreted by the animal itself, but upon the action of bacteria and of certain enzymes (cytases) that are taken with the vegetable food.

B. ABSORPTION

The carbohydrate food is absorbed for the most part as simple sugars—*monosaccharides*

1. *In the stomach* hardly any sugar is absorbed

2. *In the small intestine* the absorption mainly occurs

(*a*) *Cane sugar* and *lactose* are inverted by the action of invertase and lactase

If these substances are fed in excess, they are absorbed in part without conversion into simple sugars and may be eliminated as such in the urine. This Alimentary Glycosuria is particularly evident, when sugar is taken without any other food. Thus, it has been found by Macleod that when 17 healthy individuals were given 5 grms. of cane sugar per kilogram of body weight, it was found that the urine of 10 contained sugar one and a half-hour afterwards. The urine of three of these men also contained invert sugar, *i e.*, Dextrose and Lævulose. Cane sugar continued to be excreted for 6 to 7 hours

(*b*) *Starches* —The bulk of carbohydrate food consists of starch, and the conditions of its absorption are more favourable. The time required for the digestion of starch to Maltose and Dextrine and subsequent inversion of these into Dextrose ensures a slower and more complete absorption

500 grms. or more of starch may be digested and absorbed in the course of a day. It all reaches the blood in the form of glucose.

At this stage we may briefly consider the significance of Blood Sugar and glycogen

Blood Sugar.—That the blood contains sugar was first demonstrated by Claude Bernard When no absorption is going on, sugar in the portal blood is the same in amount as in systemic circulation. During digestion, the sugar in the portal blood is raised It is also raised in the systemic circulation, but to a less degree Between the portal blood and systemic circulation, there is some barrier, which holds back some of the sugar The information as to how these barriers hold back the excess of sugar is very inaccurate because of the difficulty of collecting blood from the portal vein without serious disturbance to the animal This has been attempted by Macleod and Fulk During the injection of a solution of sugar into one of the smaller branches of the portal vein, the blood sugar is compared in the blood of the portal vein with that in systemic circulation It has been found, that the percentage of sugar is a little less in the blood of the abdominal vena cava than that in the portal vein, and is still less in the blood of systemic veins, *e g*, Femoral vein These results justify the conclusion, that the barriers responsible for taking out the absorbed sugar from blood exists in the *liver* and *muscles* The barrier consists in the conversion of Glucose into Glycogen.

Glycogen.—In 1848 Claude Bernard discovered that an extract obtained from the liver just after death contained much less sugar than one made afterwards He subsequently concluded that the organ must contain some reserve form of carbohydrate which he called Glycogen This was a discovery of the first importance, for the formation of Glycogen is the first step in the metabolism of carbohydrates and Glycogen serves as an important reserve form of carbohydrate in the body The discovery was all the more remarkable, for it showed that a mechanism existed in animals like the one already known in plants, by which excess of sugar in the circulating body fluids is stored in the body as a reserve form of polysaccharide

Glycogen is normally present in the liver of well-fed animals varying in amount from 1 4 to 4 per cent of the weight of the liver By rich carbohydrate food it may be increased to 12 per cent After death it readily disappears owing to the action of an enzyme which converts it into Glucose This reaction is a reversible one. The liver by virtue of its glycogenic function, plays an important rôle in regulating the blood sugar level, as the following observations indicate .—

1. If much sugar is absorbed from intestine, Glycogen is deposited in the liver It seems probable that the presence of Insulin is necessary for this action This prevents the sugar in the systemic blood from rising above a certain definite level

2 If the systemic blood sugar tends to fall, liver Glycogen is mobilized and is converted into glucose This is due partly to impulses along the sympathetic nerves and partly to the secretion of adrenaline The Glycogen is converted into sugar to keep up the blood sugar at a constant level The liver Glycogen is thus diminished by —

(*a*) Exercise.
(*b*) Exposure to cold.
(*c*) Starvation.
(*d*) Injection of Phloridzin.
(*e*) Insulin Hypoglycæmia
(*f*) Injection of Adrenalin, Thyroxin and Pituitrin.

The sources of liver glycogen are —

(*i*) *Carbohydrates of the Food*—This formation of Glycogen in the liver and its subsequent conversion into glucose according to the needs of the body is one of the most interesting events in the economy of the body Certain sugars are direct Glycogen formers, namely :—

(*a*) Dextrose.
(*b*) Lævulose.
(*c*) Cane Sugar, after inversion
(*d*) Maltose, after inversion

Liver can only convert monosaccharides into Glycogen, not disaccharides

(*ii*) *Proteins*.—Protein may give rise to Glycogen under certain conditions. Certain amino-acids when given by mouth may give rise to Glycogen—such as glycine, alanine, aspartic acid, glutamic acid, etc. The amino-acids are first deaminized in the liver, and the non-nitrogenous organic acid, which remains, is synthesised to form sugar and Glycogen. The same happens in Diabetes Mallitus and in Phloridzin diabetes Under these conditions Dextrose in the urine bears a definite ratio to the amount of nitrogen in the urine The ratio is D N · 3 65 : 1 (Lusk) It indicates, that both Dextrose and Nitrogen are derived from Protein. This happens in prolonged starvation, and in the diabetic This sugar formation from protein is checked by Insulin

(*iii*) *Fats*.—There is some evidence, that glycerine acts as a direct glycogen or sugar former When fed, especially in the diabetic condition, it causes an increase in urinary sugar. The evidence is however conflicting

Functions of Glycogen.—The current view is the one advanced by Claude Bernard Glycogen forms a temporary reserve supply of carbohydrate material, which is laid up in the liver during digestion and is gradually made use of in the intervals between meals. During digestion, the Carbohydrate food is absorbed into the blood of the portal system as dextrose and lævulose If these sugars passed through the blood unchanged, the contents of the systemic blood would be increased perceptibly, causing Hyperglycæmia and Glycosuria But this excess of sugar is abstracted by liver cells, is dehydrated to make glycogen and is retained in the liver cells in this form for a short period.

Conversion of Glycogen into glucose is brought about by an enzyme *Glycogenase*, and the process is known as Glycogenolysis.

We are familiar with the view that Glycogen of the liver represents a storage form of carbohydrate But there are certain facts, which show that it is also in a sense an internal secretion. This was the original view of Claude Bernard, who believed Glycogen to be produced out of Protein He, however, did not deny that it was capable also of being formed from carbohydrate. The modern view seems to be based on this original conception of Claude Bernard In the words of Cramer, "We should look upon the Glycogen of the liver dynamically, and not, as has been done, statically, as a mere store of excess of carbohydrate." The following observations show that Glycogen seldom entirely disappears :—

1 *Effects of Starvation on Glycogen*—When food is withheld, Glycogen at first decreases rapidly and then increases again. It has been found by Hershey and Orr, that steady increase occurs during later periods of starvation

This is due to the formation of new sugar in the liver during starvation, *Gluconeogenesis*. The sources of this are protein and fat,—mainly protein

2 Although starvation alone may not cause the liver glycogen to disappear completely, it is commonly believed that it is so, if the starving animal is made to perform exercise But it has been shown by Hershey and Orr that —

(*a*) In a rat starved for 24 hours when made to work on tread mill for 23 hours, Glycogen of liver is 2 per cent.

(*b*) In 3 rabbits deprived of food for 48 hours, injected with sufficient strychnine to induce convulsions while they were under artificial respiration, the Glycogen content of the liver is :—

(*i*) .09% when convulsions lasted 38 minutes.
(*ii*) .06% ,, ,, ,, 44 ,,
(*iii*) 08% ,, ,, ,, 57 ,,

Thus the Glycogen does not disappear completely even after severe convulsions

3. In pathological conditions, it is doubtful if Glycogen ever entirely disappears. It is always found in depancreatized and fasting animals several days after they have been rendered diabetic by withdrawal of insulin.

4 After repeated injections of Thyroid, Glycogen is almost completely removed but some traces still remain.

Recent work thus shows that the storage hypothesis of the rôle of Glycogen is not enough Some facts seem to indicate that it is in a sense an internal secretion

In addition to the liver, the *muscles* are the other important seat of carbohydrate storage, but the percentage here is less than in the liver, being seldom above 1. After starvation when the liver is almost completely depleted of glycogen, it is still found in the muscles

Glucose in the food gives rise to liver Glycogen which provides glucose in general circulation, and from this muscle Glycogen is formed Muscle Glycogen does not appear to be again broken down to glucose which can pass into circulation. It is also to be noted, that as the Glycogen disappears from the liver, free sugar appears in the blood and there is no increase of lactic acid. On the other hand when muscle Glycogen disappears, there is no increase in free sugar, but lactic acid accumulates almost in proportion to the glycogen which has disappeared.

Thus, Glycogen must be regarded as an important intermediary substance in the metabolism of sugar in the body.

(C) INTERMEDIARY METABOLISM OF CARBOHYDRATES AND THEIR ULTIMATE FATE IN THE BODY

The ultimate products of combustion of sugar in the body are CO_2 and water The intermediate substances formed are not definitely known. The process is dynamic, not static. Hence at any given time any intermediate substance which may be formed is small in quantity. The knowledge of intermediate metabolism of carbohydrates therefore is still very incomplete

The work of Emden and Hopkins indicates that the probable changes in the final oxidation of sugar are :—

1. Glycogen is converted into glucose, which gives rise to Hexose Diphosphate (Lactacidogen), from which Lactic Acid is produced,

2 Lactic Acid is converted into CO_2 and water.

In the first series of changes no oxidation occurs. As regards the second change, we know chiefly from the work of A. V Hill, that in the presence of oxygen one-fifth of the lactic acid is oxidized to CO_2 and H_2O, while the remaining four-fifth is reconstructed into glucose or glycogen, presumably through the Lactacidogen or Hexose Diphosphate stage. There is a series of interlocked reactions, in which the glutathione present in muscle plays an important part In this, as in similar processes, Pyruvic acid is an intermediate product, and to a slight extent alcohol.

It is believed that when the muscle contracts, the actual contraction is simultaneous in point of time with the change from glycogen to lactic acid, and that it is produced by the osmotic changes involved through the production of a large number of small molecules from one large one and by the change in Hydrogen-ion concentration coincident with the production of lactic acid.

In the absence of sufficient oxygen, as during continued severe muscular exertion with partial tissue asphyxiation, lactic acid accumulates until a distinct muscle acidosis exists. This can be demonstrated in the fatigued muscle of frog Litmus paper applied to its cut surface is turned red The lactic acid may even pass into circulation, and in subsequent periods of rest may be reabsorbed.

It has also been shown that in the conversion of glucose into lactic acid, apart from Lactacidogen, glyceric aldehyde and Methylgloxal or both are formed as intermediate products. The conversion of Methylgloxal into Lactic Acid is due to the action of an enzyme (Glyoxylase) as shown by Dakin and Dudley The knowledge of these intermediate substances is still uncertain, but the probability is that the series of reactions is all in the direction of final oxidation into CO_2 and H_2O

Apart from this, one other substance is probably derived from glucose, namely, Glycuronic Acid It can be obtained from blood, liver, urine, etc , and exists in combination with toxic substances such as phenol or camphor. These substances are formed in the body. Whether formed in the body or given by mouth, they combine with Glycuronic acid and are excreted as such in the urine in the same way as phenol and cresol are conjugated with sulphuric acid and excreted.

(D) FUNCTIONS OF CARBOHYDRATE FOOD

1. It furnishes the main source of energy for the needs of the tissue cells and particularly for muscular work. This is the case also with nerve cells and probably all cells producing energy in the living body

2 Oxidation of sugar furnishes an important source of the constant supply of heat needed by the body Each gramme of carbohydrate on combustion gives rise to 4.1 cal. of heat.

3 Oxidation of sugar protects the protein of the body. Sugar is the most important protein-sparing food Animals can be kept in a state of Nitrogen equilibrium on a relatively small amount of protein, provided carbohydrates are also eaten

Carbohydrate is a better sparer of protein than fat

4. Excess of carbohydrate beyond the power of the tissues to store as glycogen is synthesized to form *fat*.

5. Carbohydrates may be utilized to some extent in constructive processes Thus —

(*a*) *Nucleic Acid* contains a carbohydrate group. Experiments of Osborne and Mendel show that the body can make its own Nucleic acid The carbohydrate part of it is derived from the metabolism of carbohydrates.

(*b*) Certain proteins and cerebrosides contain a carbohydrate group as part of the molecular complex

(*c*) Lactose secreted by the Mammary glands is also formed by the animal body

This in brief is the history of the carbohydrate food in the living body We may take up the thread at the stage when Glucose is circulating in the blood and study its behaviour in more detail.

III. The Sugar of the Blood.

(A) METHOD OF QUANTITATIVE ESTIMATION OF BLOOD SUGAR.

In 1775 Dobson first showed in a case of Diabetes that blood contained a sugar-like substance Claude Bernard, the most distinguished physiologist of the 19th century, and one of the greatest men that France has produced, discovered 70 years later, that sugar was a constituent of normal blood He further showed that when rabbits were made to suffer from Glycosuria by puncture of the floor of the fourth ventricle, the blood sugar rose, thus establishing a relationship between the rise of blood sugar and the occurrence of sugar in the urine.

Chiefly owing to the fact, that the methods for estimating blood sugar were rather elaborate and tedious, no great advance was made in this field, till Bang discovered his method.

At the present day a large number of methods are in vogue. They all depend on the reducing properties of glucose, and may be divided into the following groups —

1 *Titrimetric group*, in which the reduction of cupric to cuprous oxide in alkaline solution is determined by the titration of the latter. Bang's, Bertrand's and Maclean's methods with their numerous modifications belong to this group

2 *Colorimetric group*, in which the production of red colour by reduction of picric acid to sodium picramate in the presence of sodium carbonate is determined by means of a colorimeter.

In all my experiments I have employed Maclean's method for estimation of Blood Sugar for 2 cc of blood. Blood is deproteinized in an acid saline solution, and the protein is removed by filtration after addition of dialyzed iron. The sugar is estimated in the filtrate by boiling with alkaline copper solution. The quantity of cuprous oxide formed is determined iodometrically

Colorimetric methods, such as Benedict's, generally give higher results than Maclean's This is probably due to the fact, that results by these methods include substances other than glucose, such as creatinine. All methods are fairly serviceable, but it is important in a series of experiments to stick to one method, so that the results are readily comparable and thus can be relied upon. Maclean's method seems to be very popular in England and America and a large number of estimations have been reported, which have established its accuracy. One of its great advantages is that only a small quantity of blood (2 cc) is needed for estimation. This can be obtained from a finger prick, and the samples can be obtained at frequent intervals, without much discomfort to the patient. I have practised this method in Maclean's own laboratory at St Thomas' Hospital. It is to be recommended for accurate work

I also studied Hagedorn Jansen's method of Blood Sugar estimation in Professor Henrique's Laboratory at Copenhagen, and practised it in my laboratory on my return to India But the results obtained were much lower than with Maclean's method.

(B) THE NATURE OF THE SUGAR OF THE BLOOD AND THE MANNER OF ITS COMBINATION.

In using the above methods it is assumed that the reducing power of the blood filtrate is a measure of the amount of glucose present This assumption is not entirely warranted, since blood may contain other reducing sugars.

Attempts to solve this difficulty have been made on the following lines :—

1. *Fermentation with Yeast* —The difference in the reducing power of the blood before and after fermentation with yeast has been determined Any residual reduction which may result is presumed to be due to other substances than glucose.

There are several sources of error in this procedure ·—

(*a*) The yeast may itself contain reducing substances.
(*b*) It may produce them during its action.
(*c*) There is practical difficulty of making certain when the fermentation of yeast is complete.

(*d*) There is the uncertainty, that there is no other microbial action which destroys glucose.

Thus this method of yeast fermentation is open to considerable sources of error

2. *Estimation of Carbon.*—Stepp has introduced another method for detecting substances other than glucose in the blood, the principle of which is as follows —

(*a*) The proteins of blood and other colloids are precipitated by phosphotungstic acid

(*b*) The excess of the reagent is removed from the filtrate

(*c*) The amount of carbon is determined in one portion of the filtrate and reducing power in the other The carbon is also calculated from the reducing power of the filtrate

It has been found that in a great many cases, the carbon calculated from the reducing power corresponds *with* that actually obtained, thus indicating that the reducing power of the blood was due to glucose

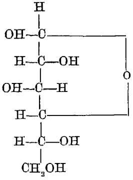
In some cases, however, carbon actually found is less than that calculated from the reducing sugar This is particularly the case in the diabetic blood This would indicate that the blood contained reducing substances with a lower percentage of carbon than glucose

For practical purposes, we may say, that the reducing power of the blood filtrate is a measure of the amount of glucose present

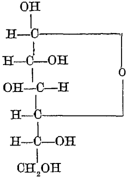
(C) THE NATURE OF GLUCOSE IN THE BLOOD

The blood contains a mixture of α and β varieties of glucose In recent years evidence has been brought forward that there also probably exists a γ-glucose, which is more reactive, differs from the others in showing greater reducing power, in rotating the plane of polarised light to the left instead of the right, and in being more unstable

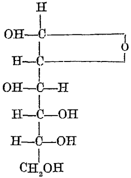
In the ordinary varieties of α and β glucose, the oxygen in the ring form of the formula is attached between the 1st and 4th (Butylene) carbon atoms. In the unstable γ-variety the linkage occurs either with the second (Ethylene) or the third (Propylene) carbon atoms.



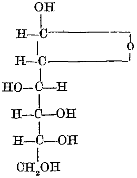
(α-*d* glucose)



(β-*d* glucose)



α form of γ-glucose
(Ethylene Oxide structure)



β form of γ-glucose
(Ethylene Oxide structure)

Hewitt and Pryde in 1920 suggested that during absorption of sugar from intestine γ-glucose is formed and is absorbed as such in the blood These results have not been confirmed by others (Steven, Weymouth, Reid, Eadie).

In 1923. Winter and Smith announced as the result of their experiments, that γ-glucose occurs in the normal blood of man and laboratory animals The evidence consisted in first removing the proteins from the blood (by Folin's reagent and alcohol) and then examining the filtrate with the polariscope which gave readings which were less dextrorotatory than they should have been, as calculated from the reducing power

These experiments were repeated by Eadie but the results were not altogether confirmatory

Further experiments by Winter and Smith show that the blood of diabetic patients, as well as of those injected with adrenalin, does not contain γ-glucose. On the contrary the polariscopic readings of blood filtrates showed greater dextrorotatory power than that calculated from the reducing power The interpretation is that these hyperglyæmic bloods contain complex sugars which have a higher rotatory but lower reducing powers than glucose The beneficial effect of Insulin in such cases is therefore believed to be due to the production of γ-glucose They conclude that the body has the power to manufacture γ-glucose from the α and β varieties. This is believed to be the result of the action of an enzyme, which is activated by Insulin

These results are highly interesting but have not received general confirmation Winter and Smith in a subsequent paper concede that a further reconsideration of the γ-glucose hypothesis is necessary There is no doubt, that research on these lines will yield valuable results.

(D) THE SUGAR COMBINATIONS IN THE BLOOD

Combination of sugar with protein is a possibility, and must be borne in mind when considering experiments regarding the nature of glucose, especially those dealing with its reducing and rotatory powers It has been shown, that sterile mixtures of glucose and intestinal mucosa (or other tissue) treated with alcohol and incubated to 120° C., and then cooled to body temperature show that the rotating power becomes less, while the reducing power is hardly affected.

But considering the contradictory results published in regard to the nature of sugar in the blood in recent years one may say that so far the evidence seems to be that all the available sugar in the blood exists there in simple solutions and that the evidence in regard to the existence of γ-glucose is still unconfirmed

(E) CONCENTRATION OF SUGAR IN THE HUMAN BLOOD WITH SPECIAL REFERENCE TO THE BLOOD OF INDIANS.

In comparing the blood sugar concentration in the blood of different animals, it is essential to bear in mind that a definite increase occurs after taking food especially that rich in carbohydrates

In order to determine the basal figure, it is necessary to estimate the blood sugar the first thing in the morning after the night's fast, or about 4 hours after the last meal. This is known as the *fasting value of Blood Sugar*

The fasting value of blood sugar in Europeans according to various workers varies from .08 to 12 per cent, the average being 0.1 per cent

The conditions in India are different from those in Europe and America Apart from marked variation in climate, one must take into consideration the dietetic habits of the vast majority of the people of this country Here a large number of persons, especially the Hindus, live on a purely vegetarian diet rich in Carbohydrates It seemed to me, that in view of the frequency of Glycosuria in this country, it was necessary to investigate how far this symptom was purely physiological depending mainly on a rich Carbohydrate diet The object of the investigation was to determine the normal blood sugar, and the tolerance for sugar in Indians living on a purely vegetarian diet, rich in Carbohydrates, as well as in those living on a mixed diet of meat and vegetables. The subjects were medical students, members of the teaching staff, and laboratory servants in the Physiology School, Grant Medical College The selection was at random, they were all normal healthy persons doing their usual daily work. It is not an easy matter to classify Indians into vegetarians and non-vegetarians, for both partake of a large quantity of Carbohydrate in their meals, the quantity being much larger than in the case of Europeans The diet of a strict vegetarian Hindu in

Bombay consists of rice, dal, vegetables of different kinds, such as potatoes, cauliflowers, cabbage, brinjal, peas, leaves of different varieties, cucumber, etc., sweets, milk and its preparations, *e.g.*, curds, butter-milk, ghee, butter, also cocoanut-oil, and fruits, such as bananas, mangoes, oranges. They all contain a large quantity of sugar In Bombay, rice and not wheat is the staple article of diet, but a certain amount of wheat is also taken in the form of chapaties and puries. On the other hand those who are not strict vegetarians do not take meat habitually and their diet also consists largely of the articles mentioned above. They take mutton, fish, chicken or eggs occasionally and on the average not oftener than once a day For practical purposes, I included all those, who never touched meat and lived habitually on dal, rice and vegetables as *vegetarians*, while those who in addition to the above took either mutton, fish, eggs or chicken at least once a day as *non-vegetarians*. No special diet was prescribed before the test. All the persons were examined under perfectly normal conditions.

The estimations were carried out after the night's fast in the morning before any meal was taken, or four and a half to five hours after the last meal, so that they were in a state of metabolic rest and variations in blood sugar following meals were not allowed to interfere with the test.

The blood was obtained from finger prick, and estimations carried out by Maclean's method for 0.2 c.c. of blood.

The subjects were between the ages of 17 and 40 years. I obtained data from 60 normal persons altogether. Of these 29 were classified as non-vegetarians and 31 as vegetarians. The results were as follows :—

(1) The average fasting level of all the 60 persons was 0.117 per cent.

(2) The average fasting level of 29 non-vegetarians was 0.107 per cent, extremes being .084 per cent and .246 per cent

(3) The average fasting level of 31 vegetarians was .125 per cent., extremes being .084 per cent and .246 per cent.

It will be seen that although the average fasting level of Blood Sugar of all the 60 persons is about the same as that of the Europeans, yet there is a slight difference between the average for vegetarians and non-vegetarians, that of the vegetarians being a little higher

The result of the Sugar Tolerance in the two cases, I will discuss later

The observations on the blood sugar of normal inhabitants in the East are not as many as one would like to have, considering the prevalence of Glycosuria in this country The following records are of special interest :—

1. McCay, Satish Chandra Banerjee, Lal Mohan Ghosal, Madan Mohan Dutta, and Charubratta Roy investigated the blood sugar and sugar in urine of the Bengalies in 1917 The average of 50 Bengalies in normal health was 0 130 per cent, the extremes being 0 087 per cent and 0 2 per cent. They ascribed this high blood sugar to excessive carbohydrate diet and want of exercise.

2 Brahmachari and Sen (1925) working on Bengalies obtained similar results

3. Van Langen also demonstrated an exceptionally high sugar content in the blood of healthy white inhabitants of the Dutch Indies and blamed the climate for this abnormality He expressed the opinion that the persons suffering from diabetes should not immigrate to the Tropics

4. S M Ling reports observations on 250 Chinese, and says that the average blood sugar in the Chinese is 095 per cent.

Fœtal blood sugar exists at a lower level of concentration than that of the mother, but rises near the time of birth

In healthy infants, 3 to 5 hours after nursing the amount varies from .085 to 125 per cent. the mean being 107 per cent.

(F) CONCENTRATION OF THE SUGAR IN THE BLOOD OF LOWER ANIMALS

1 *Dog* (A carnivorous animal)

(*a*) The fasting blood sugar of 9 dogs in the Physiological Laboratory, Grant Medical College, was determined The results are as follows :—

			Blood Sugar Per cent.
Dog No. 1	(Male)	.	0.072
,, No. 2	,,	.	0.074
,, No. 3	,,	.	0.072
,, No. 4	,,	..	0.063
,, No. 5	,,		0.063
,, No. 6	(Female)	..	0.072
,, No. 7	,,	..	0.072
,, No. 8	,,	.	0.072
,, No 9	,,	..	0.072

Average blood sugar of 9 dogs— 07 per cent, extremes being 0.063 per cent to 0.074 per cent

(*b*) Cammidge and Howard estimated the blood sugar of 9 dogs and found average fasting level to be 0 083 per cent, extremes being 0.074 per cent and 0.090 per cent.

(*c*) Oppler and Rona estimated the blood sugar of 4 dogs and found the average to be 0 085 per cent, the extremes being 0.073 per cent and 0.102 per cent.

(*d*) Macleod and Pearce estimated the blood sugar immediately after etherization and found the average to be 0.111 per cent, the extremes being .075 per cent and .146 per cent The latter which is a little higher level, may be due to the effect of the anæsthetic.

(*e*) Embden, Luthge, and Liefmann estimated the blood sugar in unæsthetized dogs and found 0.051 per cent and 0 088 per cent as the extremes.

Thus, most of the observations seem to show that the average blood sugar of dogs ranges from .07 to .08 per cent

2. *Rabbit.* (A herbivorous animal)

(*a*) The blood sugar of 7 rabbits was estimated in my Laboratory. The results are as follows .—

			Blood Sugar Per cent
Rabbit	No. 1	(Female)	0.10
,,	No. 2	,,	0.10
,,	No 3	,,	0.072
,,	No. 4	,,	0 072
,,	No 5	,,	0.072
,,	No 6	,,	0 102
,,	No 7	,,	0 10

The average blood sugar of 7 rabbits therefore is 0 088 per cent, the extremes being 0 072 per cent and 0 102 per cent

(b) Cammidge and Howard estimated the blood sugar of 25 rabbits and found the average blood sugar to be 0 083 per cent, the extremes being 0.080 per cent and 0.096 per cent.

(c) Jones working with Maclean's method found the average blood sugar of 16 rabbits being 0.068 per cent and 0.116 per cent

(d) Scott and Ford found the average of 27 rabbits to be 0.118 per cent.

(e) Eadie found the average of 157 rabbits to be 0.116 per cent

All the above figures agree very closely.

The blood sugar level of rabbits varies considerably under normal conditions. There is an interesting observation of Cammidge on record showing that these animals are peculiarly liable to emotional disturbances, which raise the percentage of blood sugar in these animals A rabbit showed fasting blood sugar value of 0.096 per cent on many occasions After a meal of oats and cabbage its blood rose to 0.138 per cent. The next day its blood sugar gave the same fasting value, but shortly after it had its usual feed of oats and cabbage it was frightened by the sudden entry of the Inspector of Vivisection into the Laboratory On this day its blood sugar one hour after the meal was 0 176 per cent, which was much higher than usual.

J. P Bose and Acton while studying the variability in rabbits used for the assay of Insulin found the average blood sugar to be 0.11 per cent. The animals consisted of white rabbits, Brown Belgian hare rabbits and the black and white variety They found a marked difference in these animals in regard to the reduction of the amount of blood sugar after insulin and they ascribed this variation to the colour of the animal The white rabbit was least affected by insulin, while the black and white varieties had convulsions due to Hypoglycæmia These animals are very liable to get a rise of blood sugar owing to fright, which is due to the increased output of adrenalin

3 *Frogs*—(*a*) In the Physiological Laboratory, Grant Medical College, the blood sugar of 13 frogs was estimated. In 4 the blood was obtained from the Sinus Venosus directly, and in 9 from the Femoral Vein The results are as follows:—

(*i*) *Blood from Sinus Venosus* (Rana Tigrina)

	Blood Sugar. Per cent.
Frog No. 1	0.164
,, No 2	0.164
,, No. 3	0.164
,, No 4	0.170

(*ii*) *Blood from the Femoral Vein* (Rana Tigrina).

	Per cent
Frog No 5	0.028
,, No 6	0.028
,, No 7	0.028
,, No 8	0.028
,, No. 9	0.028
,, No 10	0.028
,, No 11	0.028
,, No. 12	0.028
,, No 13	0.028

The blood sugar in the femoral vein was uniformly 0.028 per cent, while it was much higher in the blood obtained directly from the sinus venosus, the average being 0.165 per cent.

This difference is very significant, and further investigations are in progress I think, the difference is probably due to the fact, that the blood in the sinus venosus is mixed largely with that coming from the liver, while that in the femoral vein is poor in sugar owing to its having circulated through the tissues, where a good deal of the sugar has been consumed

Differences in the blood sugar content of the venous and arterial blood of man have also been noted, the amount being slightly higher in the arterial than in the venous blood

(*b*) Bang estimated the blood sugar in the Rana Temporaria and Esculenta and found the amount to vary from 0.02 per cent to 0 05 per cent These figures agree very closely with those obtained by me in the blood from the Femoral vein of Rana Tigrina

4 The blood sugar of most mammals is on the average 0 1 per cent It is a little higher in birds, being about 0 203 per cent in chicken and fowl. It is also found in the blood of fish, the amount being relatively higher in the river fish as compared with the deep-sea fish

(G) DISTRIBUTION OF SUGAR BETWEEN THE CORPUSCLES AND PLASMA.

Two methods are employed to investigate this problem :—

1. *The Direct Method.*—This consists in :—
   - (*a*) Centrifuging the blood immediately after removal from the body
   - (*b*) Pipetting off the Serum or Plasma.
   - (*c*) Washing the residue with isotonic saline.
   - (*d*) Determining the sugar separately in Plasma and residue.

This method is not satisfactory because :—

- (*i*) It is difficult to precipitate all the proteins from the corpuscular sediment.
- (*ii*) Washing the corpuscles alters the sugar concentration within them The sugar tends to diffuse from the corpuscles into the saline solution.

(*iii*) Glycolysis occurs rapidly in the sediment and leads to a considerable lowering of sugar concentration

2. *The Indirect Method*—This consists in —

(*a*) Measuring the sugar contained in a sample of blood

(*b*) Measuring the sugar contained in a sample of plasma obtained by rapid centrifuging

(*c*) Measuring the proportion of corpuscles to plasma by the Hæmatocrite

Having obtained these data, it is easy to calculate the concentration of sugar in the plasma and corpuscles The indirect method is more satisfactory than the direct In recent work the following technique has been adopted :—

(*a*) Blood is centrifuged in a ligatured portion of a large vein; or it is received into paraffined tubes and centrifuged. The corpuscles are thus separated

(*b*) The percentage of sugar is determined in the whole blood and plasma separately, and the percentage in the corpuscles is calculated by the difference

Even according to this method some error is likely to arise Separation of corpuscles from the plasma should be rapid, since there is a tendency immediately after the blood is shed for the equalization of concentration to take place by diffusion.

Upto about 1921, it was thought that the amount of sugar in the plasma and corpuscles is approximately the same. But Hogler and Ueberrack state, that in the rabbit the proportion of sugar in the corpuscles is very small as compared with that in the plasma. By using anticoagulant, it has been found that the human corpuscles contain 0 05 to 0 08 per cent sugar. If stringent precautions are taken to obviate diffusion and the living test tube method is used for centrifugalizing blood, the amount in corpuscles in man is found to be 0.06 per cent, and in plasma 0.25 per cent The difference is also marked in the blood of dog

In the blood of diabetic patients, it has been found by Frank, that the plasma decidedly contains more sugar than corpuscles.

It is interesting to note, that washing the corpuscular sediment causes the corpuscles to lose the power of absorbing glucose. Some change takes place which reduces their permeability to glucose

On the whole it would appear that in the passage of sugar through the membrane of the corpuscles the same laws hold good which are applicable to the diffusion of sugar into issue cells generally.

The present consensus of opinion seems to be that the corpuscles contain very much less glucose than plasma.

Glycolysis in the Blood —After blood is shed, there is a tendency for the blood sugar to disappear This varies with the temperature of the blood and the species of the animal. Thus in normal dog s blood at body temperature 50 per cent sugar disappears in two and a half hours, while much less disappears in the blood of normal pig, sheep and rabbit As a rule it is more marked in the blood of carnivora than herbivora.

There is evidence that glycolysis is depressed in the blood of diabetic patients Denis and Giles have investigated this relationship between glycolysis and diabetes. In severe cases *glycolysis* is much diminished, and is practically absent in coma.

The following factors hasten the process of Glycolysis .—

1 Agitation of blood In unagitated blood the process is comparatively slow

2 Bubbling free oxygen through blood. Absence of oxygen, however, does not stop the process.

3. In centrifuged deposit of blood the process occurs rapidly.

4. Suspension of Leucocytes (*e g*, sterile pus diluted with Lock's solution) has a high glycolytic power Red blood corpuscles also show it in the absence of white blood corpuscles,

The following factors retard Glycolysis:—

1 Potassium Oxalate in concentration of 0.1 per cent or over
2 Fluorides
3. Plasma or serum free from leucocytes
4. Frequent washing of red blood corpuscles by centrifuging with isotonic saline deprives them of their Glycolytic power At the same time it renders them incapable of absorbing glucose This suggests that Glycolysis is an intracorpuscular process.

Glycolysis does not occur in the fish blood.

Hirudin has no effect on the process. There seems to be some relationship in the blood of different animals between the rate of glycolysis and the permeability of red blood corpuscles to glucose For instance, glycolysis is poorly developed in the blood of rabbit, the corpuscles of which are impermeable to glucose, whereas it is rapid in the blood of the dog, in which the permeability of the corpuscles is high

The glucose which disappears during Glycolysis is either broken down to non-reducing sugar derivatives or polymerised to form disaccharides or lower dextrines Mellanby has shown that Lactic Acid accumulates in the blood after removal from the body, which also explains the diminution in the alkaline reserve which occurs.

The importance of Glycolysis from a practical point of view is that in making blood sugar estimations care should be taken that no glycolysis occurs in the blood after its escape from the body and during the experimental procedure, otherwise the results would not be reliable

Source of Sugar of the Blood.—I have already described the source of glycogen in the body The sugar of the blood, which amounts to 0 1 per cent approximately in a fasting individual is derived mainly from the carbohydrates of the diet, which are absorbed as glucose in the portal circulation. While circulating through the liver, the excess of glucose is converted into glycogen. This mechanism keeps the concentration of sugar in systemic circulation within certain definite limits. According to the needs of the body this glycogen is reconverted into glucose by the action of glycogenase. After death this process of glycogenolysis is very much accelerated, but during life it is kept under control If for some reason or other there is weakening of glycogenesis, or excess of glycogenolysis, it may lead to Hyperglycæmia and Glycosuria

There is evidence, as already mentioned, that Glycogen and blood sugar may be formed from non-carbohydrate material also, namely, proteins or fats, a process known as *gluconeogenesis* Studies in the Respiratory Quotient show that this occurs in normal animals When carbohydrate is undergoing metabolism R Q is 1. It is 0 8 with protein and 0.7 with fat metabolism During starvation, it often becomes less than 0 7, showing that oxygen is retained in the body. This retained oxygen is incorporated into substances having a high oxygen content Proteins and fats contain only 12 to 20 per cent of oxygen, while carbohydrate contains about 53 per cent The retained oxygen, therefore, must under those conditions be utilized in the conversion of part of protein and fat into carbohydrate material

In severe Diabetes Mellitus, blood sugar continues to be high even when all carbohydrate food is withheld Under these conditions, sugar is derived from proteins in the body, Gluconeogenesis occurs Diabetes can be induced by the injection of Phloridzin in an animal The direct effect of the drug is to produce increased conversion of glycogen into glucose There is no Hyperglycæmia, but marked Glycosuria. After a time, when all stores of glycogen have been exhausted sugar excretion stops and remains remarkably constant There is now a definite ratio between the amount of glucose and nitrogen excretion This D N ratio becomes 1 3.65 when glycogen is completely exhausted, and the sugar is derived from protein. It is maintained as such when the animal is fed on protein This is a very valuable method of ascertaining the source of blood sugar. Experiments on phloridzinized animals have shown that sugar may be formed from Glycol Aldehyde, Glycerol, Lactic Acid, Propyl Alcohol, Methylglyoxal, Alanine, Glycocoll, Aspartic Acid, Glutamic Acid, etc.

Thus, we may say, that in addition to carbohydrates, the proteins and, to a certain extent, fats may be the source of the sugar supply in the body.

Concluding Remarks—These are some of the main facts about the physiological significance of blood sugar We have considered the rôle of carbohydrates in the diet, their digestion, absorption, intermediary metabolism, and ultimate fate in the body I have dealt with the methods for estimating blood sugar, and have discussed its nature, the question of its distribution between plasma and corpuscles, the phenomenon of Glycolysis, etc As regards the normal amount of blood sugar, I have pointed out my own observations, which show that it is slightly higher in the case of those Indians who are 'vegetarians' than in 'non-vegetarians'. Many more normal data should be obtained in India. There is a great necessity for investigating the normal physiological constants in the inhabitants of this country. The data given for Europeans and Americans would not do for us, for there are important climatic, dietetic, environmental and other differences.

The consideration of the *source* of blood sugar leads us to the question of the influence of diet and other factors on it. This together with the Sugar Tolerance Test and the variations in the amount of blood sugar in health and disease, we shall consider in the next lecture

LECTURE II.

(*Chairman* · DR B. K. NARAYAN RAO.)

MR. CHAIRMAN, LADIES AND GENTLEMEN,

The sugar of the blood is derived mainly from the carbohydrates of the food While describing the procedure for estimating blood sugar, I said, that it was necessary to bear in mind that a definite increase occurs after taking food, especially that rich in carbohydrates. We may consider now more fully what this effect is :—

1 *Effect of Food on Blood Sugar.*—A number of observations were carried out in my laboratory to study the behaviour of blood sugar after an ordinary meal. The fasting level of blood sugar of the following three laboratory servants was first estimated Then each of them took their ordinary meal and the blood sugar was estimated at half-hourly intervals afterwards.

1. KESHAV

		Per cent
Blood Sugar	Fasting Level	0 081
Do	Half hour after meal	0 114
Do	One do.	0 109
Do	One and a half hours after meal	0 079
Do	Two hours do	0 088

The meal consisted of rice, tomatoes, mutton-curry, curd, chapatties, onion, pickles and one banana Total weight, two and a quarter pounds

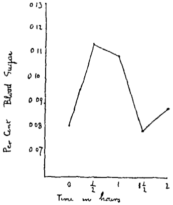


Fig. 1.

Keshav Effect of Food on Blood Sugar.

2. SITARAM.

		Per cent
Blood Sugar	Fasting Level	0 079
Do	Half hour after meal	0 109
Do	One do	0.109
Do	One and a half hours after meal	0 079
Do	Two hours do	0 089

The meal consisted of rice, dal, and vegetables. Total weight, two and a quarter pounds.

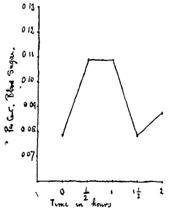


Fig. 2.

Sitaram Effect of Food on Blood Sugar

3. JAIRAM GOPAL

		Per cent
Blood Sugar	Fasting Level	0·078
Do.	Half hour after meal	0·102
Do	One do	0·102
Do.	One and a half hours after meal	0·078
Do.	Two hours do	0·079

The meal consisted of rice, dal and vegetables. Total weight, one pound ten ounces.

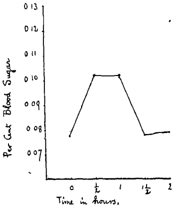


Fig. 3.

Jairam Gopal Effect of Food on Blood Suger.

All these three cases show that after an ordinary meal there is a moderate rise of Blood Sugar, which reaches its maximum about thirty minutes after the meal The amount then abruptly falls, reaching the original fasting level in about one and a half to two hours. During the day after every meal there is a rise followed by a fall. This increase is specially marked after a carbohydrate meal, namely, rice, bread, potatoes, sugar, sweets, etc. After a mixed meal, the amount of rise in blood sugar depends largely on the amount of carbohydrate in the diet

The Sugar Tolerance Test—Based on the above physiological fact that blood sugar rises after a carbohydrate meal, various tests for sugar tolerance have been devised. At the present moment the test which is most widely practised and which gives most valuable information is that introduced by Maclean

Coelho and I carried out certain investigations on the Sugar Tolerance on Indians with the method advocated by Maclean :—

1. The experiments were performed on normal persons after the night's fast, or four and a half to five hours after the last meal.

2 The blood was obtained from the finger prick and estimated for blood sugar by Maclean's method for 2 c.c of blood At first the fasting level of blood sugar was estimated. Then 50 grms of glucose (pure Merck's) dissolved in 150 c.c. water was given by mouth.

3 Blood sugar was estimated at half-hourly intervals for two hours after the administration of glucose

4 Urine was examined for sugar before and at one-hourly intervals after the administration of glucose.

I have some observations in which 50 grms of cane sugar was given instead of 50 grms of glucose

Altogether, I have records of 60 normal persons (Indians) in whom the Sugar Tolerance Test was carried out The ages were between 17 and 40 years. All the subjects were roughly divided into non-vegetarians and vegetarians as explained in the previous lecture in order to ascertain the effect of diet on Sugar Tolerance

1 The average data obtained from all the 60 persons so examined are as follows —

		Per cent
Blood Sugar	Fasting Level	0 117
Do.	Half hour after glucose	0 161
Do	One do	0 142
Do	One and a half hours after glucose	0 129
Do	Two hours do	0 115

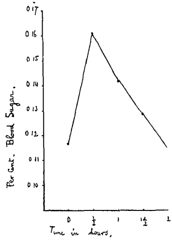


Fig. 4.

Sugar Tolerance Test Average Data from 60 Normal Persons.

2 Out of 60, 29 were non-vegetarians, from whom the following average data were obtained :—

		Per cent
Blood Sugar	Fasting Level	0 107
Do	Half hour after glucose	0 155
Do.	One do.	0 138
Do	One and a half hours after glucose	0 117
Do.	Two hours do	0 103

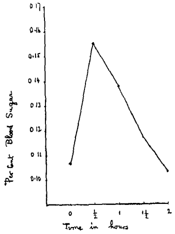


Fig. 5.

Sugar Tolerance Test **Average Data obtained from 29 Non-Vegetarians**

3 Out of 60, 31 were vegetarians, from whom the following average data were obtained:—

		Per cent
Blood Sugar	Fasting Level ..	0 125
Do	Half hour after glucose ..	0 167
Do	One do . .	0 151
Do	One and a half hours after glucose	0 139
Do	Two hours do. .	0 126

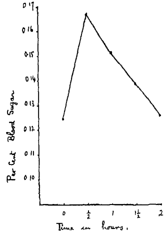


Fig. 6.

Sugar Tolerance Test **Average Data from 31 Vegetarians.**

These observations show that the average fasting level of blood sugar in Indians is slightly higher than the figure quoted for European countries, namely, 0.1 per cent. There are slight but definite differences amongst Indians according to diet, the pure vegetarians having a slightly higher level of blood sugar than non-vegetarians

The Sugar Tolerance Test shows the same characteristics as those reported for European countries. After giving glucose by mouth, there is commonly an increase in blood sugar amounting to 30 to 40 per cent of the normal This may be called Postprandial Hyperglycæmia It reaches its maximum in about 30 to 60 minutes after glucose, then it falls abruptly reaching the preglucose level in one and a half to two hours. In the first curve the maximum reached is 0 161 per cent, in the second 0 155 per cent, in the third 0.167 per cent. Thus the maximum varies somewhat, and it may be noted that it is slightly higher in the vegetarians than in the non-vegetarians Immediately after the maximum concentration is reached a sudden change takes place. The blood sugar falls and in one and a half to two hours it is at the preglucose level. In some cases it is actually lower

Effect of Age.—(*a*) It is found that in children under three years of age, the rise in blood sugar is less marked The maximum concentration is seldom above 0.12 or 0.13 per cent

(*b*) In children above three years, it shows the same sort of curve as in the adult.

(*c*) In old age, the curve is more prolonged, and even after two or three hours the blood sugar may be above the preglucose level, *i e*, 0.13 or 0.14 per cent.

Influence of Sex.—There is no difference in the Sugar Tolerance Curve of men as compared with that of women.

It may be observed that blood sugar after 50 grms of glucose is seldom above 0.18 per cent in normal adults

Effects of different Sugars on Blood Sugar Concentration— I investigated the effects of the following sugars in addition to glucose, on the blood sugar concentration of normal persons :—

1. Cane Sugar.
2. Lævulose
3. Galactose

1. *Cane Sugar* gives practically the same sort of Sugar Tolerance Curve as glucose. The curves, however, are not so regular. Cane sugar is readily inverted by the invertase in the Succus Entericus into Dextrose and Lævulose and is absorbed as such. Of the 13 individuals examined, there was a rise in blood sugar in all except one in the first half hour. The maximum rise was perhaps a little higher and a little more delayed than in the case of glucose. The slight fall in the first half hour observed in one case may have been due, as Cammidge suggests, to relative increase in the alkaline bases of the blood produced by the secretion of Hydrochloric Acid into the stomach. The blood sugar generally comes down to the normal level after two hours.

2. *Lævulose.*—It is well known that when lævulose is given by mouth, it does not produce any rise in blood sugar, as it is readily converted into glycogen in the liver. For this reason it is employed to test the efficiency of the liver. If the liver is deranged, lævulose produces a rise in blood sugar like glucose. It may also be pointed out that in a well-established case of diabetes, lævulose produces a rise in blood sugar and gives the same sort of curve as glucose. The following observations on three normal persons may be noted :—

No 1 A.

			Per cent
Blood Sugar Fasting Level			0.101
Do.	Half hour after 50 grms. Lævulose		0.101
Do.	One	do	0.094
Do.	One and a half	do	0.10
Do.	Two	do	0.101

Urine.—No sugar in urine prior to the administration of lævulose. Slight trace in samples collected afterwards at intervals of one and two hours as tested with Benedict's method.

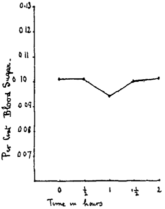


Fig. 7.

'*A*' Effect of Administration of 50 grms. of Laevulose on Blood Sugar

No. 2 'B'

			Per cent
Blood Sugar	Fasting Level		0.10
Do	Half hour after 50 grms Lævulose		0.10
Do	One	do	0.10
Do	One and a half	do	0.096
Do	Two	do	0.1

Urine.—No sugar in urine prior to the administration of lævulose Slight trace in the two-hourly sample, as tested with Benedict's method

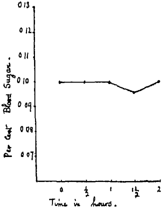


Fig. 8.

'*B*' Effect of Administration of 50 grms. of Laevulose on Blood Sugar.

No 3 'C'

			Per cent
Blood Sugar	Fasting Level		0 089
Do	Half hour after 50 grms Lævulose		0 094
Do	One	do	0 10
Do	One and a half	do	0 10
Do	Two	do	0 089

Urine—No sugar in urine prior to the administration of lævulose Both the one- and the two-hourly samples showed definite reduction, as tested with Benedict's method

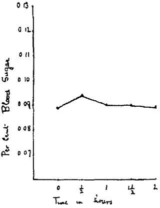


Fig. 9.

'C' Effect of Administration of 50 grms. of Laevulose on Blood Sugar

It will be seen, that there is no rise of blood sugar after administration of laevulose in any of the three cases observed. The blood sugar remains almost at the prelaevulose level throughout. It may be noted that in all the three individuals there was a slight trace of reducing sugar in the urine after the administration of laevulose Supposing that lævulose is readily converted into glycogen in the liver the tests show that the liver of these cases was functioning efficiently.

3 *Galactose*—The influence of galactose on the behaviour of blood sugar and sugar in the urine was investigated in five normal persons. The results are as follows:—

No 1 S.R'.

			Per cent.
Blood Sugar	Fasting Level		0.084
Do	Half hour after 50 grms Galactose		0.138
Do	One	do	0.108
Do	One and a half	do	0.12
Do	Two	do	0.085

Urine.—No sugar prior to the administration of Galactose. One-hourly sample after galactose contained 0.7 per cent reducing sugar, and the two-hourly sample 2.2 per cent.

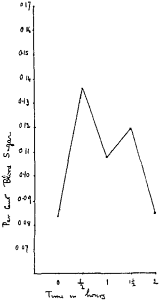


Fig. 10.

No. 1 'S R': Effect of Administration of 50 grms. of Galactose on Blood Sugar.

No. 2 'B'.

			Per cent
Blood Sugar	Fasting Level		0 129
Do.	Half hour after 50 grms. Galactose		0 129
Do.	One	do	0 152
Do.	One and a half	do	0 149
Do.	Two	do	0.089

Urine.—No sugar prior to the administration of Galactose. One-hourly sample after galactose contained 1 2 per cent reducing sugar, and two-hourly sample 2.9 per cent

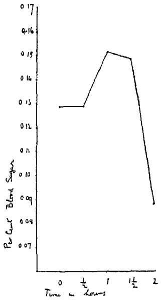


Fig. 11.

No. 2 'B'· Effect of Administration of 50 grms. of Galactose on Blood Sugar.

No. 3 'B.L.'

			Per cent
Blood Sugar	Fasting Level.		0 082
Do.	Half hour after 50 grms. Galactose	.	.. 0 164
Do.	One	do	. .. 0 109
Do.	One and a half	do.	. 0.129
Do.	Two	do.	.. . 0.107

Urine—No sugar prior to the administration of Galactose One-hourly sample after galactose contained 1 1 per cent reducing sugar, and two-hourly sample 2.7 per cent

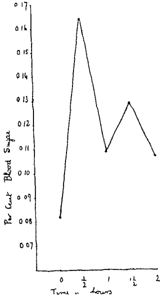


Fig. 12.

No 3 'B L' **Effect of Administration of 50 grms. of Galactose on Blood Sugar.**

No 4 'D'.

			Per cent.
Blood Sugar	Fasting Level		0 094
Do	Half hour after 50 grms Galactose		0 109
Do	One	do	0 116
Do	One and a half	do	0 134
Do	Two	do	0 10

Urine—No sugar prior to the administration of Galactose One-hourly sample after galactose contained 1.3 per cent reducing sugar, and the two-hourly sample 1.79 per cent.

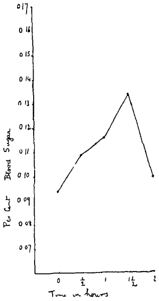


Fig. 13.

No 4 'D' Effect of Administration of 50 grms of Galactose on Blood Sugar

No. 5 'C'.

			Per cent
Blood Sugar	Fasting Level		0 107
Do.	Half hour after 50 grms Galactose		0 152
Do.	One	do	0 129
Do	One and a half	do	
Do.	Two	do.	0.10

Urine.—No sugar prior to the administration of Galactose One-hourly sample after galactose contained 1 5 per cent reducing sugar, and the two-hourly samples 2.7 per cent

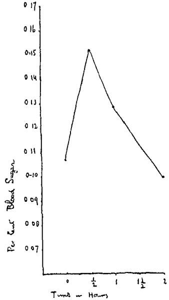


Fig. 14.

No. 5 '*C*' **Effect of Administration of 50 grms. of Galactose on Blood Sugar.**

It will be observed that in all the five individuals the blood sugar rose after the administration of 50 grms of galactose. The maximum was reached in half to one hour and then it fell reaching the fasting level in about two hours. Some observers have stated that there is no rise of blood sugar after galactose, but this is contrary to my experience

The interesting feature of the observations, however, is that all the five individuals, who originally were aglycosuric, showed considerable amounts of sugar in the urine after the administration of galactose, ranging from about 0 7 per cent to 2 9 per cent. Sugar in the urine was estimated with Benedict's method. This occurrence of glycosuria after administration of galactose is significant.

Effects of Administration of two successive doses of Glucose on Blood Sugar.—In addition to the above experiments, I carried out certain observations on the effects of administration of two successive doses of glucose on blood sugar The usual dose of 50 grms. of glucose was given twice at an interval of two hours. The records of four experiments are as follows:—

No 1 'K R P'

			Per cent.
Blood Sugar	Fasting Level		0 086
First dose of 50 grms Glucose given			
Blood Sugar	Half hour after first dose		0 11
Do.	One	do.	0 068
Do	One and a half	do	. 0 11
Do	Two	do	0 085
Second dose of 50 grms. Glucose given			
Blood Sugar	Two and a half hours after the first dose		0 09
Do	Three	do	. 0 106
Do	Three and a half	do	0 087

Urine.—No sugar prior to the administration of Glucose, in the two-hourly samples slight trace of reducing sugar present

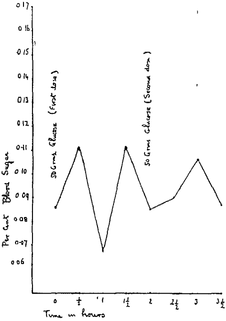


Fig. 15.

No 2 'B. M. K'

			Per cent
Blood Sugar Fasting Level			.. 0 085
First dose of 50 grms Glucose given			
Blood Sugar	Half hour after the first dose		0 112
Do	One	do	0 129
Do	One and a half	do	0 075
Do	Two	do.	0 064
Second dose of 50 grms Glucose given			
Blood Sugar	Two and a half hours after the first dose		0 087
Do	Three	do	0 106
Do	Three and a half	do	0 087

Urine—No sugar prior to the administration of Glucose Slight trace in the two-hourly and three-and-a-half hourly samples

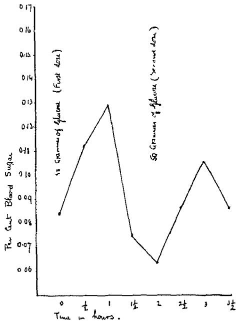


Fig. 16.

'*B M. K*' Effect of Administration of two doses of 50 grms. each of Glucose at an interval of two hours on Blood Sugar.

No. 3 'D. G. A.'

			Per cent
Blood Sugar	Fasting Level.		0.085
First dose of 50 grms Glucose given			
Blood Sugar	Half hour after the first dose		0.16
Do	One hour	do	0.158
Do	One and a half	do	0.062
Do.	Two	do	0.081
Second dose of 50 grms Glucose given.			
Blood Sugar	Two and a half hours after the first dose		0.111
Do	Three	do	0.113
Do.	Three and a half	do.	0.093

Urine.—No sugar prior to the administration of Glucose Slight trace in the two-hourly and three-and-a-half-hourly samples.

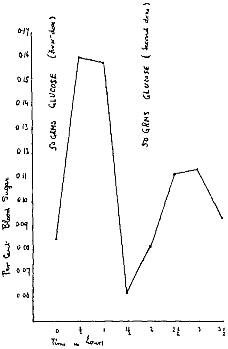


Fig. 17.

'*D G A*' Effect of Administration of two doses of 50 grms. each of Glucose at an interval of two hours on Blood Sugar.

No 4 'J. G. T.'

			Per cent
Blood Sugar	Fasting Level		0.085
First dose of 50 grms Glucose given			
Blood Sugar	Half hour after the first dose		0.161
Do	One	do.	0.146
Do	One and a half	do	0.066
Do	Two	do	0.072
Second dose of 50 grms. Glucose given			
Blood Sugar	Two and a half hours after the first dose		0.134
Do	Three	do	0.092
Do	Three and a half	do	0.084

Urine.—No sugar prior to the administration of Glucose Slight trace in the two-hourly sample.

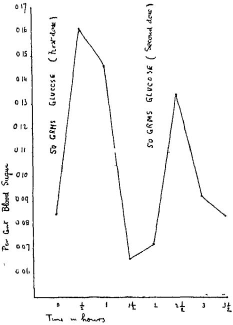


Fig. 18.

'J. G. T.': Effect of Administration of two doses of 50 grms. each of Glucose at an interval of two hours on Blood Sugar.

It will be observed, that after the first dose there is a considerable rise of blood sugar. After two hours, when the blood sugar has come down to the preglucose level, the second dose of glucose produces a second rise, which, however, is less marked than the first After three and a half hours the blood sugar has come down to the fasting level. It may also be noted that in all the four subjects there is a definite trace of sugar in the urine, although originally they were all aglycosuric.

Causes of changes in Blood Sugar after administration of Glucose—We may now consider the causes of the changes in the concentration of blood sugar after administration of glucose

The rise in blood sugar after a dose of glucose is due, no doubt, to the absorption of sugar into the blood of the portal vein, which reaches the systemic circulation after passing through the liver. The same happens after the in-take of Carbohydrate meal. We do not know definitely what the actual nature of the sugar in the blood is. The rise continues till it reaches a maximum, and then it falls back to its original level This fall may be due, as De Wesselow puts it, to the following causes :—

(*a*) Cessation of its absorption

(*b*) Its oxidation in the tissues, *e.g.*, muscles and glands

(*c*) Its conversion into Glycogen (or fat) and storage as such.

(*d*) Its excretion by the kidneys.

All these processes do not operate in an equal degree.

1 As regards the first possibility, the absorption does not stop in half to one hour, as sugar can still be obtained by stomach pump at the end of that period Beeler, Bryan, Cathcart and Fitz have introduced a more elaborate technique for carrying out the Sugar Tolerance Test In this, information is obtained as to the actual amount of sugar absorbed by removal of unabsorbed sugar at the end of the first hour, the amount of which is estimated According to this method also, the same sort of curve is obtained as that by the simple method advocated by Maclean.

The fact that in cases of diabetes the blood sugar does not come down to its preglucose level after two hours also indicates that it is not cessation of absorption that is responsible for the fall

2. The second factor, namely, oxidation of sugar in the tissues is also of doubtful value There is a rise in Respiratory Quotient within half to one hour indicating increased combustion It appears at the point where the fall in blood sugar commences and continues for some time after. This combustion accounts only for a small fraction (about 18 per cent) of the total sugar absorbed within two and a half hours. It does not wholly account for the sudden fall in the curve. Besides, if oxidation of sugar occurred on a large scale soon after the administration of glucose, it would be a very wasteful procedure.

3. The conversion of glucose to glycogen chiefly accounts for the fall in blood sugar Glycogen is formed in the liver and muscles out of glucose in the blood, and the rapidity with which this conversion and consequent storage take place explains the fall in blood sugar The storage mechanism comes into play when blood sugar reaches a certain level known usually as *Renal Threshold*, so that in normal persons no glycosuria occurs. This aspect of the question I will deal with presently Lævulose which is a good glycogen-former does not produce any rise in blood sugar owing to the readiness and rapidity with which it is converted into glycogen Lævulose, therefore, has been used to test the efficiency of the liver

4. Excretion by the kidney does not account for the fall, for the amount lost in urine is very small, if any, in normal individuals The readiness, however, with which glycosuria is established in many cases under my observation would show that a certain amount is lost in this way, but it would not account by any means for the fall in blood sugar after the first half to one hour

Therefore, the evidence goes to show that the fall in the curve is mainly due to storage of glucose as glycogen in the liver.

Value of Sugar Tolerance Test in cases of Diabetes.—A typical Sugar Tolerance Test carried out in my laboratory in a case of diabetes is as follows —

M S

			Per cent
Blood Sugar	Fasting Level		0 207
Do	Half hour after a dose of 50 gms Glucose		0 313
Do	One	do	0 38
Do	One and a half	do.	0 34
Do.	Two	do	0 250

Urine.—Before the administration of glucose urine contained 6.2 per cent of sugar In the first-hour sample after glucose, the amount was 7 1 per cent

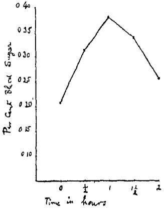


Fig. 19.

'*M S*' Diabetes Mellitus.

It will be observed that :—

(*a*) The fasting level of blood sugar is higher than normal

(*b*) The blood sugar rises to a much higher level than in the normal individual.

(*c*) The blood sugar, even after two hours, is higher than the preglucose level The fall in the curve takes place much more slowly and gradually than in the normal person.

These three features are typical of a diabetic curve. The curve gives an idea as to the extent and duration of Postprandial Hyperglycæmia, and it serves as a more certain index of the efficiency of sugar metabolism than merely an examination of the urine for sugar In early diabetes the curve rises higher, stays up for a longer time and does not return to normal for several hours. Slight deviations from the normal should not be given too much weight If in any given case we find that postprandial hyperglycæmia is higher than normal and that it stays up longer we are justified in warning the patient to restrict his in-take of carbohydrate. *This persistent postprandial hyperglycæmia is the earliest sign of diabetes* It may be that in such early cases there is a transient or no glycosuria, but the excess of sugar in the blood after each meal throws an undue strain on the glycogenic function of the liver, and may lead to persistent glycosuria. The condition progresses, the postprandial hyperglycæmia after one meal has not subsided before the next meal is taken, so that increase in blood sugar produced by the first meal becomes superadded to the second. The curve of blood sugar rises higher until at last permanent hyperglycæmia is established

This test is also valuable in judging the course of treatment, for the aim of modern treatment of diabetes is to establish as far as possible such conditions, that a curve very much like that of the normal individual is obtained.

The Relation of Blood Sugar to Sugar in Urine.—It is of the utmost importance to know the conditions under which sugar appears in the urine, and the relation which urinary sugar bears to blood sugar.

According to the modern conception of renal secretion (Cushny's), it is held that by a process of filtration, a protein free filtrate of blood plasma is produced in the glomerulus It contains all the non-colloidal constituents of blood plasma As this filtrate trickles down the convoluted tubule a process of selective absorption occurs Substances like urea which are of no further use to the body are not reabsorbed, they are known as *Non-threshold substances*, while other substances such as sugar and sodium chloride are reabsorbed as the body needs them. These are called *Threshold substances* Sugar thus is one of Cushny's Threshold Substances

This theory is not altogether satisfactory It does not, for instance, explain the ratios of the different substances in blood and urine Further while claiming to be a mechanistic conception, originally based on Ludwig's views, it savours of a neo-vitalism in so far as the property of selective absorption ascribed to tubular epithelium is concerned Recent work has thrown a great deal of light on the problem, and a more satisfactory hypothesis than Cushny's is awaited

It is held at the present day that so long as blood sugar is at the ordinary fasting level of 0.1 per cent or so, no sugar appears in the urine Even if the blood sugar rises to a certain extent, the kidney may still be able to hold it back, and none may be excreted If, however, the level of blood sugar rises to 0.18 per cent or over, glycosuria occurs. So long as blood sugar is below 0.18 per cent glycosuria does not occur This level of 0.18 per cent is known as the renal threshold for sugar. As pointed out already this is also the level when glycogenesis actively occurs in the liver, so that excess of sugar is stored as glycogen and the liver thus prevents the blood sugar from exceeding the renal threshold

From the data from my own experiments which I have placed before you, it would also seem that in normal persons the blood sugar seldom reaches 0.18 per cent or over after administration of glucose. There are cases, however, when the blood sugar may reach 0.20 per cent or 0.22 per cent in the normal, but it soon falls, and at the end of two hours it is at or below the preglucose level Such a case, from my records, is the following .—

			Per cent
Blood Sugar	Fasting Level		0.123
Do	Half hour after 50 grms Glucose		0.22
Do	One	do	0.181
Do	One and a half	do	0.165
Do	Two hours	do	0.16

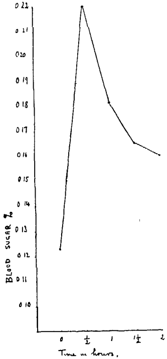


Fig. 20.

'Lag' Curve

The blood sugar went above the renal threshold and Glycosuria occurred. This type of curve is known as the 'Lag' curve.

The condition, however, is not serious, as the return of blood sugar to normal is not delayed.

This is the accepted view regarding the *Renal Threshold*, but my own observations throw a considerable doubt on this hypothesis

A large percentage (about 40 per cent) of normal persons on whom the Sugar Tolerance Test has been carried out by me show evidence of Glycuresis, when blood sugar reaches the neighbourhood of about .17 per cent. Maclean states that in healthy subjects with normal kidneys no excretion of sugar takes place, until the concentration of blood sugar reaches 0.18 per cent. If that be the case, it seems to me that the group of Indians I have examined show a poorer tolerance for carbohydrates than inhabitants of European countries, and that non-vegetarians on the whole have a better tolerance than vegetarians. The renal threshold also seems to be lower. It is more in the neighbourhood of .17 per cent. But I do not believe in the fixity of the renal threshold. It varies in different individuals. It would be more correct to say, that it lies between 15 per cent and 18 per cent, but that no definite fixed limit can be laid down. This conclusion is also borne out by the observations of Feinblatt on 2,000 routine examinations.

Further, the influence of other sugars, namely, lævulose and galactose on blood sugar, is interesting. As shown already, lævulose when given by mouth does not produce any rise in blood sugar, and yet a trace may be found in the urine. Galactose, on the other hand, when given by mouth causes hyperglycæmia, as well as marked glycosuria. There appears to be no definite renal threshold for these sugars, and if there be one, it is lower than that for glucose.

Recently interesting observations have been reported by Cori and Cori in regard to the absorption of various sugars. Experiments were performed on white rats. They were kept for some time previously on standard diet, and then starved for 24 or 48 hours. Then 2 or 3 c.c. of strong solution of sugar was passed into the stomach through a catheter from the mouth. The animals were killed at varying intervals afterwards, and the rate of absorption was found by subtracting from the amount of sugar given that which remained in the intestinal tract.

Absorption of sugar takes place as already mentioned in the intestine and not at all in the stomach. Cori and Cori state that when sufficient sugar is given, the amount of sugar absorbed is the same from hour to hour, upto four hours. The co-efficient of absorption (number of grms. of sugar absorbed per 100 grms. of body weight per hour) is characteristic for each sugar It varies according to the time the animal is starved prior to the test, and is independent of the strength of solution. The co-efficients of absorption of different sugars are as follows —

1 AFTER 48 HOURS STARVATION.

	grms
d—galactose	0 196
d—glucose	0 178
d—fractose	0 077
d—mannose	0.034
l—xylose	0 028
l—arabinose	0 016

2 AFTER 24 HOURS STARVATION

The co-efficient for glucose is 266 grms.

These figures show a high selectivity. The behaviour of blood sugar and glycuresis may depend to a certain extent on the co-efficient of absorption of these sugars In view of the fact that galactose produces glycosuria so readily, it is interesting to note that of all the sugars mentioned above it is absorbed most readily and has the highest co-efficient of absorption

The selectivity of absorption depends markedly on the structure of the sugar molecule and the renal threshold also depends on the same factor

Recent research has clearly established that normal urine contains traces of sugar Benedict, Osterberg and Neuwirth have shown, that, in an apparently healthy person having no diabetic tendency, as much as .6 per cent of sugar may be present after a breakfast rich in carbohydrates, and in 24 hours the total sugar passed in urine may amount to 1.586 grms. (184 per cent). If the same person is given an ordinary mixed diet, the total sugar may approximate to 1 grm per day The output of sugar in urine after a meal follows a curve similar to that of blood sugar, but slightly delayed in time. In both there is an increase followed by a decline There is a close relationship between the percentage of blood sugar and sugar in urine. Benedict has even shown that each meal is followed by a rise in urinary sugar irrespective of the nature of the diet, suggesting that ordinary digestive processes have an accelerating effect on glycogenolysis

The fact that both the blood sugar and urinary sugar rise after a carbohydrate meal has been confirmed by several observers.

In some cases it has been found, that although glucose within the assimilation limits does not produce glycosuria, yet when large quantities of preserved fruit and sweetmeats are taken, there is a distinct glycuresis The same is the case with galactose, which markedly increases the reducing power of urine It seems that neither the tissues nor the kidneys have the power of holding back this sugar. It leaves the blood as quickly as it is absorbed from the intestine

Lactose behaves in a manner intermediate between sucrose and galactose

Excess of glucose leaves the blood slowly, because the tissues are already supplied with it When the renal threshold for sugar is markedly reduced, the condition of renal diabetes occurs, which is not so uncommon in this country

Precise determination of the renal threshold is, thus, very difficult I may invite your attention to the work of Goto and Kuno (1921) They made observations on 53 Japanese subjects Plasma was used for sugar determination Twenty-two of the subjects showed sugar in the urine after taking 100 grms glucose in 250 c c water the first thing in the morning.

The renal threshold was as follows :—

In 8 men . Between 180 and 190 per cent.
In 5 men .. Between .160 and .172 ,, ,,
In 8 men . Between .128 and 155 ,, ,,

The sugar having first appeared in the urine as the result of hyperglycæmia remained in it long after the blood sugar came down This has been observed by others also, (Bailey, Folin and Berglund) These observations confirm my own findings which were published in 1925. It would seem that although the upper limit 0.18 to 0.19 per cent is easy to fix, the lower level can be much less definitely placed In some cases there may be a mild transient glycosuria after every meal, (Faber and Norgaard).

Certain interesting experiments of Cori and Cori on the white rat and in the mouse show that the sugar tolerance is lowered in the summer months The animals were anæsthetised with Amytal The tolerance was 2 5 grms per K G of weight, and this was associated with a certain degree of Ketonuria

While considering this question of Sugar Tolerance and Renal Threshold I would like to refer to some observations of Porter and Langley, which are interesting They examined 50 normal individuals on the following plan ·—

> Ten cases each of decade starting at thirty to forty of mixed men and women were taken Each case was starved overnight, and the starving blood sugar level was estimated , 50 grms. glucose in 100 c c water were given, and the blood sugar estimated at the end of each half hour for two and a half hours, the urine being examined at the expiration of that period The following table gives the results of these tests .—

Age	1	2	3	4	5	6
	Before.	Hour	Hour	Hour	Hour	Hour
Under 30	0 080	0 170	0 125	0 080	0 080	0 080
30—40	0 105	0 184	0 174	0 153	0 150	0 140
40—50	0 120	0 192	0 207	0 165	0 155	0 152
50—60	0 146	0.225	0 218	0 195	0 166	0 155
60—70	0 145	0 225	0 238	0 245	0 205	0 185
70—80	0 115	0 175	0 190	0 185	0 165	0 130

The curves obtained from these figures demonstrate the following points .—

1. That the starving blood sugar level tends to rise from the normal 0.08 per cent of youth to nearly 0.15 per cent at 70 years of age

2 That the actual increment of sugar-content of the blood, however, remains the same, and is always less than 0 1 per cent

3 That at the ages considered, the highest point of sugar concentration is liable to be reached at the end of 1 hour, rather than at the end of half hour as is usual in youth.

4 That there is an increasing delay in return to the starving level, which fails to occur in the two and a half hour period of observation

5. That in the decade 30—40 years of age, urinary sugar in response to 50 grms glucose is not found, but in the decades above this glycosuria in response to this amount of sugar occurs in about 30 per cent of tests, being rather higher in the decade, 60—70 years of age, when it is nearly 40 per cent

6 In the decade 70—80, the type of curve obtained differs greatly in that it does not rise so high, but takes considerably longer to return to starving level. No explanation of this is offered, but the patients were senile

They concluded that glucose tolerance curves should be interpreted not only from the point of view of the blood sugar rise and the period occupied in returning to starvation level, but also with due regard to the age of the patient The increased lag in the curve, apart from age considerations, might easily lead to an opinion of Potential Diabetes, when in reality it is believed that the delay is the physiological result of age This is particularly liable to be misleading in patients complaining of such troubles as pruritis, and sciatica, which may or may not be dietetic in origin.

The threshold value for sugar for normal kidney which may be placed somewhere between 0 15 and 0 18 per cent, is not easy to account for Certain observations of Hamburger are of interest in this connection. He performed certain perfusion experiments on frogs' kidneys, and came to the conclusion that glucose occupies a peculiar position among isomeric monosaccharides with regard to glomerular epithelium, suggesting the relation of a key to a lock. According to him, the geometrical configuration of the glucose molecule gives to it those properties which cause it to be retained in circulation by the healthy kidney He further found that the permeability of glomerular epithelium for sugar could be diminished or increased in experiments with frog's kidney, perfused with Ringer's Solution, if the proportion of inorganic constituents in the perfusion fluid were altered In this respect the concentration of free calcium-ions and sodium bicarbonate are important factors When free calcium-ions reach a certain concentration the kidney becomes impervious to glucose, but when this is altered it becomes permeable

It was also found that in the absence of sodium bicarbonate the kidney became very permeable and no glucose was retained

As regards the permeability of the kidney to dextrose, calcium and sodium seem to have opposite effects and it follows that the composition of the blood as regards calcium and sodium and also its acid base equilibrium are important factors in sugar excretion. This threshold value which is generally regarded as 0 18 per cent of blood sugar, is distinctly lower in a great many normal individuals I have examined. It lies between 0 155 and 0 17 per cent In fact, my own work and recent observations by others show that the hypothesis of a fixed renal threshold for glucose cannot be accepted It shows marked individual variations

Hyperglycæmia —The normal fasting level of blood sugar varies under many conditions. According to increase or decrease the condition may be one of hyperglycæmia or hypoglycæmia

Hyperglycæmia occurs under the following conditions:—

1. ALIMENTARY HYPERGLYCÆMIA.

The rise in blood sugar after ingesting glucose or a meal rich in carbohydrates is known as alimentary glycosuria. The phenomena was described by Bang in animals in 1913. Similar observations were made on men by various observers (Jacobson, Maclean and De Wesselow, Folin and Berglund), and on this the sugar tolerance test, I have just described, depends.

I wish to draw your attention particularly to this condition It is of special importance to us in this country, since in my experiments, the fact has been well brought out that in Indians, and especially in those who live on a rich carbohydrate diet, vegetarians, this alimentary or postprandial hyperglycæmia is high and that in many cases it is associated with glycosuria. Excessive carbohydrate diet throws a great strain on the glycogenic functions of the liver In early stages of diabetes there may be no defect in the pancreas, but merely a deficiency of the storage mechanism of the liver

Thus, alimentary glycosuria may occur, as the result of the liver being flooded habitually by an excess of the digestive products of the carbohydrates of the diet Apart from this, it may also occur, if there is any impairment of the glycogenic function of the liver acquired or inborn Such factors operate very frequently in this country, where so many diseases occur which throw a strain on the liver, *e.g*, Malaria, Dysentery, etc. Rich carbohydrate diet and sedentary habits of life are responsible for the large frequency of glycosuria in this country It is therefore mainly dietetic in origin, and for this reason can be readily controlled

If alimentary hyperglycæmia is allowed to continue, there is no doubt that the activity of the Islets of Langerhans is overstrained, which eventually break down, and thus the well-known condition of diabetes mellitus results

2 NERVOUS HYPERGLYCÆMIA

(A) *Piqure*—In 1857 Claude Bernard punctured the floor of the 4th ventricle in well-fed rabbits and found that this was followed by marked glycosuria which lasted several hours. On the basis of this and similar experiments it is believed that there is a nerve centre (Glycogenic Centre) which controls the process of glycogenolysis in the liver, and the glycosuria is explained as being due to this increased glycogenolysis

This so-called puncture diabetes can be easily produced by puncturing the medulla between the roots of origin of 8th and 10th cranial nerves.

The blood sugar rises rapidly. It reaches its maximum in an hour, and remains elevated for some time It finally falls and regains the normal level in 6 or 8 hours, although sometimes it may remain up for 24 hours Considerable sugar appears in the urine within an hour of the puncture.

The current view is that this centre stimulates the process by which glycogen is converted into glucose in the liver

It may be pointed out, that Insulin prevents the Piqure Hyperglycæmia.

(B) There is evidence to show that efferent impulses travel from the centre to the liver by way of the splanchnic nerves

The following observations are of interest:—

(i) Cavazzani brothers (1894) showed that blood sugar in hepatic veins is increased by stimulation of the coeliac plexus.

(ii) Macleod (1906) found in well-fed rabbits, that there was increase in sugar in arterial blood after stimulation of the splanchnic nerve on the left side just after its entry into abdomen There was marked hyperglycæmia associated with glycosuria and diuresis Still more marked effect was observed on placing the electrodes on the uncut nerve than on stimulating the peripheral end of the cut nerve This effect may be due to —

(a) The direct control of nerves on the glycogenic function of hepatic cells, or

(b) The discharge into the blood of some hormone which excites glycogenolysis, or

(c) Glycogenolysis may be secondary to asphyxial condition resulting from marked vasoconstriction.

Experiments show that splanchnic hyperglycæmia is due to the hypersecretion of adrenalin, for if the suprarenals are extirpated, stimulation of the splanchnic nerve does not produce hyperglycæmia.

As I shall mention presently, injection of adrenalin also produces hyperglycæmia.

(*iii*) The afferent nerves are probably provided in the vagus nerve But the demonstration is difficult, for stimulation of the vagus sets up marked respiratory disturbances which in themselves may produce hyperglycæmia. This question needs to be investigated further.

(C) Recently Camus, Gournay and La Grand have produced experimental diabetes by introducing a capillary tube filled with fatty acids into the pituitary region in rabbits The paraventricular neucleus and neucleus of the tuber were affected frequently The effect was glycosuria and polyuria. A lesion of the tuber causes a more lasting and graver diabetes than Claude Bernard's puncture

There is both a nervous and a hormone control so far as the glycogenic function of the liver is concerned. When sudden increase of sugar in the blood is required, the glycogenic centre sends out impulses, which not only directly excite the break down of glycogen in the liver, but also stimulate the suprarenals to secrete more adrenalin into the blood, thus augmenting the action of the nerve impulse

This dual control of glycogenic function of liver by nerve and hormone is not unique for a similar mechanism exists in the case of —

(1) Secretion of gastric juice (Gastrin and nerves).

(2) Pancreas (Secretin and nerves).

It may be that nerves control the transitory changes in sugar production, while the hormone (adrenalin) is responsible for changes of a more permanent character related to the general metabolic requirements of the tissues

3. INFLUENCE OF PANCREAS, THYROID, PITUITARY, SUPRARENAL AND PARATHYROID GLANDS ON BLOOD SUGAR.

1. *Pancreas* —β cells of the Islets of Langerhans produce an internal secretion, Insulin, which has a profound effect on carbohydrate metabolism. When injected into an animal it produces a fall of blood sugar. The disease, Diabetes Mellitus, is believed to be pancreatic in origin and therefore I will deal with it in the next lecture. Suffice it to say, that removal

of Pancreas experimentally produces a condition very much analogous to diabetes mellitus, which is accompanied by hyperglycæmia and glycosuria.

2. *Thyroid Gland*—(*a*) The removal of the thyroid gland leads to diminution of Blood Sugar and reduces hyperglycæmia produced by the removal of the pancreas.

(*b*) Thyroid feeding in normal animals diminishes tolerance for carbohydrates, and blood sugar is raised. The Respiratory Quotient is raised indicating increased combustion of sugar

(*c*) Glycosuria is often a symptom of exophthalmic goitre. This is accompanied by hyperglycæmia There is diminished tolerance for carbohydrates in hyperthyroidism, and this is due largely to defective storage mechanism

(*d*) In thyroid deficiency sugar tolerance is variable. In cretinism it is increased, in myxœdema it may be either increased or diminished, but the renal threshold is generally raised

3. *Pituitary Body*—Injection of the active principle of the posterior-lobe (pituitrin) results in hyperglycæmia. Extracts of the anterior-lobe have no such effect In acromegaly, hyperglycæmia and glycosuria are as a rule developed.

In Frolich's Disease, the condition as regards blood sugar resembles hypothyroidism. There is generally increased tolerance for carbohydrates.

4. *Suprarenal Body.*—Action of this has already been referred to under nervous hyperglycæmia Injection of adrenalin leads to hyperglycæmia and glycosuria. The result is marked if the liver contains much glycogen. The effect is due to increased glycogenolysis in the liver.

In animals who have been starved and the liver glycogen is much reduced the injection of adrenalin causes glycogen to accumulate in the liver cells. This is an interesting result and will throw some light on the true significance of glycogen in the body.

In adrenalin hyperglycæmia there is decrease in the blood diastase, and increase in the liver diastase, so that not only is excess of sugar discharged in the liver, but less is destroyed in the blood.

5 *Parathyroid Glands* have no effect on blood sugar.

4. ASPHYXIAL HYPERGLYCÆMIA AND HYPERGLYCÆMIA DUE TO ANÆSTHETICS AND NARCOTICS.

1 It is a well-known fact that in asphyxia blood sugar is raised and glycosuria also occurs, provided the liver contains sufficient glycogen. This is due largely to deficiency of oxygen (anoxaemia), although excess of CO_2 also plays a part. The actual mechanism is probably this. Owing to slight changes in hydrogen-ion concentration in blood in asphyxia, the glycogenic centre is first excited which leads to increased glycogenolysis Later when asphyxia is still more marked, the hepatic cells are directly effected by the increased H-ion-concentration. The convulsions also help the process, leading to increased glycosuria and hyperglycæmia. Hypersecretion of adrenalin may be a contributory factor

2 *Anæsthetics and Narcotics* —(*a*) Asphyxia is usually responsible for the rise of blood sugar in anæsthesia. Hypersecretion of adrenalin may be a factor.

The degree of hyperglycæmia is proportional to anaesthesia. This is specially the case with ether Asphyxia plays a rôle here If oxygen is given with ether, the hyperglycæmia is less marked.

(*b*) Morphine and urethane also produce increase of blood sugar.

It is important to note .—

(*i*) That isoamylethylbarbituric acid (amytal) does not produce rise in blood sugar This is a useful anæsthetic for animals, on whom experiments on carbohydrate metabolism are to be performed Its dose is 0.1 grm. per kilo in dogs and 0.08 to 0 1 grm per kilo in rabbits.

(*ii*) That insulin prevents the rise of blood sugar resulting from asphyxia and anæsthetics, and it also prevents the development of hyperglycæmia due to poisoning by CO.

Hypoglycæmia occurs under various conditions —

I. RENAL GLYCOSURIA.

As mentioned already, this is a condition in which the renal threshold is lowered and the patient suffers from glycosuria when the blood sugar is far below 0 18 per cent. There is an increased permeability of the kidney to glucose. The condition is fairly common. The urine may contain 2 per cent of sugar when the blood sugar content is 0.1 per cent or 0 12 per cent, or lower. The usual symptoms of diabetes are as a rule absent If Hamburger's hypothesis regarding the renal permeability to glucose be accepted, this condition would be due to a lower percentage of calcium in the blood. Cammidge records some cases in which there was a diminution of calcium in the blood in such cases This has an important bearing on treatment Cases of renal glycosuria have been treated by Cammidge by allowing ordinary mixed diet, $\frac{1}{10}$ grm Parathyroid nightly and 5 grains of calcium chloride three times a day after meals with some improvement

It might be pointed out that, in dealing with this condition, care should be taken not to confuse it with early cases of true diabetes, for the treatment of the two conditions is quite different.

II. HYPOGLYCÆMIA DUE TO INSULIN INJECTIONS.

An injection of Insulin in the diabetic or normal subjects is followed by an immediate fall of blood sugar, reaching its maximum in 2 to 4 hours Certain dangerous symptoms, which may ultimately be fatal, result if the blood sugar falls below a certain minimum (0.045 per cent) I will deal with this condition in more detail in the next lecture

III. HYPOGLYCÆMIA RESULTING FROM INJURY TO THE LIVER

When the liver is cut out from circulation, symptoms of muscular weakness, twitchings, generalized convulsions and death supervene. The blood sugar falls, and symptoms generally come on when its level is about 0 04 per cent The condition is relieved by administration of glucose.

IV. It has been observed that renal threshold for sugar is lowered sometimes in early diabetes and pregnancy

Apart from these the following conditions may effect the blood sugar concentration :—

(A) The fall of blood sugar occurs in Hydrazine poisoning and severe chloroform poisoning owing to damage to the liver. Ergotanin also lowers it Disodium phosphate given with glucose produces a less rise in blood sugar, than glucose alone. Phosphates assist in the formation of glycogen from glucose When glycogen is stored, the retained phosphorus is excreted giving rise to increased elimination

In Addison's Disease, there is usually Hypoglycæmia associated with lowered blood pressure In normal rabbits application of warmth produces first a rise and then a fall of blood sugar. In fasting infants under two weeks old and in ill-nourished children generally low values of blood sugar are generally obtained

(B) The rise of blood sugar is caused by Atophan, Atoxyl, and Caffein, also by intravenous injections of small amounts of proteins in rabbits and by anaphylactic shock in dogs In infection with Enteritidisparatyphosus—B group the blood sugar is high, which may be due to associated lesions in the pancreas Injection of potassium chloride, and of 10 c c. of 10 per cent calcium chloride in some cases may be accompanied by a rise. Acid sodium phosphate given with glucose produces a greater rise of blood sugar, than glucose alone In arthritis, malignant disease of the gastro-intestinal tract, and in severe dyspepsia in infants the blood sugar is generally high

Having considered the main facts about the behaviour of blood sugar from a physiological point of view, I shall deal in the next lecture with the problem of Diabetes with special reference to Indians.

LECTURE III.

DIABETES MELLITUS WITH SPECIAL REFERENCE TO ITS PREVALENCE IN INDIA.

(*Chairman*. DR. B. K. NARAYAN RAO.)

MR. CHAIRMAN, LADIES AND GENTLEMEN,

Diabetes Mellitus is a common malady in medical practice in India. The cases present themselves in diverse ways. Some of the common types are these.—

A man aged about 40 years or over, obviously fat and overweight, comes to you complaining of general weakness or debility, excessive thirst, polyuria, frequent micturition, good appetite, and frequently constipation. His general condition is good. The symptoms have come on gradually, and he cannot state their duration definitely. On examination of the urine sugar is found. Acetone is usually absent. Mild cases sometimes do not complain of anything at all, and it is usually at a medical examination for Life Assurance or one of the Public Services, that the condition is first recognized.

The surgeon often meets with the cases first, for they go to him for the relief of carbuncles, boils or gangrene of the foot, or for cataract.

A different type of case is a young lad of 10 or 15, who is thin and underweight, complains of much weakness, thirst, polyuria, and frequent micturition The symptoms are acute, and the onset is usually sudden. The patient ascribes them to the after-effects of an attack of ' fever ', and can generally remember when they commenced. The urine on examination is found to be loaded with sugar and contains acetone bodies.

Or finally, the case might come in an unconscious state, picked up by friends or the police. The patient is comatose. His respirations are slow and deep, the type generally known as 'air-hunger '. The pulse is feeble. There is smell of acetone in the breath. You draw out a specimen of urine with a catheter, and find that it contains a large amount of sugar and acetone bodies

The common feature of all these types is the presence of glycosuria, the existence of which has been recognized since ancient times

History of Diabetes.—The existence of sugar in the urine was known to the ancient Hindus According to Hirsch the earliest accounts of sweet urine come from India It was known as 'Madhu Meha' or 'honey urine', and is described in Ayur-Veda The Hindus noted the symptoms of thirst, foul breath and languor

In the papyrus of Ebers, a copy of an Egyptian medical compilation, there is mention of a disease with polyuria Aretæus the Cappodocian (150 A.D.) has given a classical description of the disease. He practically named the disease, the word being derived from a Greek word, διαζητης which means syphon, owing to the fact that the intake of water did not remain long in the body, and flowed right through it He noted the marked loss of flesh, polyuria, lassitude and marked thirst and considered diabetes a form of dropsy.

Claudius Galenus (131 A.D) considered it to be a form of kidney disease, in which the kidneys had lost the power to retain water

There are references to it by the Mohammedan and Jewish physicains Avicenna (980-1037 A.D.), known as the Prince of Physicians, gave a good account of diabetes and noticed that the diabetic urine tasted sweet.

Rhazes (850-992), an Arabian Physician, gave buttermilk and malt extract and advised the avoidance of physical and mental strain.

Viaticum perigrinantes of Ibn-el-Ischezzar (1004) contains a remarkable account of the disease, in which thirst, polyuria and voracious appetite are mentioned but not the sweetish urine.

Paracelsus (1493-1546) considered diabetes a condition in which there was an increased formation of salt in the blood, which irritated the kidneys.

As we pass into the 17th century, that period in the history of diabetes commences, when a number of observers helped to establish a definite diagnosis

1 *Thomas Willis* (1621-1675), after whom the arteries at the base of the brain are described as the Circle of Willis, made the best qualitative examination of the urine that was possible in his time. He tasted the urine and described it to be 'wonderfully sweet, as if containing honey or sugar' This established the basic principle for diagnosis between Diabetes Mellitus and Diabetes Insipidus

The real cause of sweetness, which Willis failed to recognize, was discovered 100 years later by Dobson (1776), who carried out various experiments on diabetic urines and found that they underwent alcoholic fermentation and observed that sweetness was due to sugar He evaporated a large amount of a patient's urine, and obtained a whitish cake, weighing 4 ozs., which behaved like ordinary sugar. Thus the presence of sugar was definitely established

Another 60 odd years passed, when Bouchardat and Peligot (1838) proved that the sugar of diabetic urine was grape-sugar or glucose

In modern times the pathology and treatment of diabetes have been rendered a chemical problem. Peters, in 1857, discovered acetone in the urine of diabetics; Kussmaul, in 1874, discovered the presence of acetone in blood and was the first to describe the diabetic coma. which is associated with Acetonæmia and 'air-hunger'. Stadelman, in 1883, discovered the relationship of β-oxybutyric acid to diabetic coma. In this connection the names of Kulz, Minkowski, and Magnus Levy should also be mentioned. In 1886, Von Mering produced experimental diabetes by injection of Phloridzin Then came the dietetic studies of Carl Von Noorden (1895-1911), of Graham Lusk (1898-1915), Benedict and Joslin, and the effect of fasting treatment of F. M. Allen (1915).

The work of Claude Bernard, to which I have already referred, is of paramount importance His discoveries of the presence of sugar in the blood, the relation of high blood sugar with glycosuria, and the glycogenic function of the liver are classical In 1889, Von Mering of Cologne made the epoch-making discovery in collaboration with Minkowski, that the removal of pancreas from an animal produced the same condition as severe diabetes mellitus in man These experiments showed beyond doubt that the pancreas is necessary for carbohydrate metabolism and that the disease of pancreas would result in diabetes In 1869, Langerhans described the cell islets in the pancreas, which are known after his name. It was by Laguesse in 1893, and Diamare in 1895, that the view was first put forward that the Islets of Langerhans were endocrine organs. This was supported by Sir E Sharpey-Schafer in 1893, who in 1916 suggested that the internal secretion of the Islets be called 'Insuline' Attempts had been made from time to time to obtain this hormone from the Islet tissue It was, however, not until 1921 that Banting in Professor Macleod's Laboratory at Toronto, took up the problem in association with Best and discovered this hormone 'Insulin'. It reduces blood sugar in experimental diabetes in animals and in diabetes mellitus in man It is one of the most remarkable discoveries in the domain of Therapeutics in the first quarter of the 20th century

Having thus briefly considered the chief landmarks in the history of this disease, we may now consider some aspects of its prevalence in India.

Diabetes in India —The disease is common in India especially in the middle and upper classes In the lower working classes it is less so It is the experience of most physicians here that it is commoner in India than in Europe The precise statistics, however, are not available The type of the disease, which is common, is the mild and chronic variety in the middle-aged and the old The acute variety in the young also occurs but is less frequent I have seen cases of the latter severe variety myself.

Stott made enquiries from the various administrative heads of the Medical Departments in the various provinces and from the statements received, estimates the number of diabetic out-patients attending the government hospitals in each province per 10,000 out-patients attending for all diseases. The results are set out in the following table :—

PROPORTION OF DIABETIC ATTENDANCES AT HOSPITALS IN VARIOUS INDIAN PROVINCES.

Order.	Provinces	Average number of out-patients treated in 1 year (average 1914-1926)		Diabetic out-patients per 10,000 of total out-patients
		All cases.	Diabetics	
1	Madras .	8,001,722	5,215	6.5
2	Bombay .	2,572,834	1,072	4.2
3	Bengal . .	7,115,540	2,033	2.9
4	Punjab .	5,352,322	1,290	2.4
5	United Provinces .	6,263,709	1,261	2.0
6	Nagpur (C. P.) .	2,234,776	411	1.8
7	Burma .	2,012,852	333	1.7
8	Assam . .	1,670,823	165	1.0

It will be seen that roughly in Madras there are six diabetic attendances per 10,000 out-patients, in Bombay 4, and in Bengal 4. In the Punjab, United Provinces and Central Provinces, there are approximately 2 attendances, while in Assam there is 1. Diabetes is therefore commoner in Madras, Bombay and Bengal, all low-lying areas, where the diet is chiefly rice, and the climate is hot and moist, and consequently not conducive to physical exercise. In provinces such as Punjab, United Provinces and Central Provinces, where the climate is drier and dietetic habits are different (rice not being the staple diet) diabetes is less common.

My own experience confirms this. I think that two important factors responsible for the frequency of diabetes in this country are excessive consumption of carbohydrates in the diet, and lack of physical exercise. The climate in the low-lying areas along the coast is apt to encourage sedentary habits, and consequently the disease is commoner there. It is less common in the poor labouring classes than in the well-to-do

Race—It is well known that race has a definite place in the etiology of this disease. Thus, it is commoner amongst the Jews than Christians in European countries In India there is evidence, that the Hindus are far more subject to diabetes than Mohammedans or Europeans In Calcutta, according to Stott, the diabetic death rate per 10,000 Hindus is about 5 times higher than the rate in Mohammedans The Insurance mortality returns show, that the diabetic deaths per 100 lives at risk are 8 for Hindus, compared with 3 for Mohammedans and 2 for Europeans in India. This markedly higher mortality amongst the Hindus is due largely to the greater amounts of carbohydrates consumed, as well as to less active habits of life

It is further calculated from the statistics of Insurance Companies that the recorded diabetic death rate for Indians is four times higher than among Christians living in India as worked over an average of the past ten years If death from carbuncle and gangrene be added to each group, the Indian death rate is about six times higher than the European death rate

These statistics also show that diabetes stands as the fifth commonest cause of death amongst the better classes of Indians, the first four causes being Influenza (pandemic of 1918), Pneumonia, Apoplexy and Phthisis. In many cases, Phthisis, Pneumonia, etc., are terminal events in a case of diabetes, and consequently diabetes plays much greater havoc than the above statistics would have us believe.

Other predisposing factors are:—

1. *Obesity*—In persons who are over-weight, it is often found that the sugar tolerance is diminished In India, a well-to-do over-fed person, who does not take enough exercise puts on weight, and often falls a victim to glycosuria. The liver and pancreas are over-strained. For a time they faithfully discharge their duties, but ultimately break down, and

lead to a diminished tolerance for sugar, and ultimately diabetes

The average working class man in this country is thin and lean, and that is the true physiological type in the tropics. A thin lean person offers a greater body surface area for heat loss, and his cooling power is proportionately greater than that of the obese type. He does manual work, and although he too lives on a rich carbohydrate diet (mostly, rice, dal, vegetables and sweets) his tissues are able to burn up all the available sugar; and no undue strain is thrown on the liver and pancreas He thus suffers less from glycosuria and diabetes than the middle class person who takes less physical exercise and is inclined to be fat. Thus in the hospital class of patient the disease is not so common as in private practice.

2. *Heredity.*—This certainly plays an important part. Obesity often seems to be a family characteristic. Most observers are of opinion that owing to family diathesis, the β-cells of the islets of Langerhans of persons with a diabetic family history, degenerate readily under dietetic excesses They, therefore, need greater care to guard against those factors, which favour the onset of diabetes. In India it is commonly seen, that cases of diabetes occur in the same family for a number of generations

3. *Age.*—In India the disease is commoner in the middle-aged, and a majority of the cases are seen in persons between the ages of 30 and 45 years. It, however, does occur in the young, in whom it is much more serious

4. *Climate.*—Hot tropical climate as such very likely reduces the tolerance for sugar As mentioned in my last lecture, the observations of Cori and Cori show that in rats the tolerance for sugar is lowered in summer months Van Langen also claimed to have demonstrated an exceptionally high sugar content in the blood of the healthy white inhabitants of the Dutch Indies, and blamed the climate for this abnormality. He is of opinion that the diabetic should be warned not to immigrate to the tropics

5 *Nervous Strain, Worry and Anxiety.*—In the last lecture, I referred to Nervous Hyperglycæmia in animals. This has a special interest in regard to human diabetes. There is apparently a special mechanism in the body, consisting of a glycogenic centre in the floor of the fourth ventricle, the vagus and the splanchnic nerves, by which the glycogen stores of the body are mobilized This mechanism is intimately associated with the output of adrenalin. There is evidence, that a relationship exists between certain clinical varieties of human diabetes and repeated stimulation of glycogenolysis by nervous influences The blood sugar often rises as the result of emotional excitement If this is repeated there may be a permanent rise of blood sugar level Hence the rôle of mental worry and anxiety and various neurotic conditions in the etiology of diabetes is an important one. Inherited predisposition to neurotic conditions also plays a part Thus the disease is common in those who are subject to much nervous strain The condition of a diabetic person also becomes worse as the result of a nervous shock

In India the disease is common in the professional classes, namely, lawyers and doctors, and in business-men. It is increasing in men of this class who are engaged in occupation demanding much mental concentration and strain

It is interesting to know that the mere strain of an examination may cause glycosuria Thus Cannon has found that there was glycosuria in four out of nine students after a severe examination, and only in one of them after an easy examination.

Pathology of Diabetes—Insulin —Diabetes is a condition of perverted metabolism not only of carbohydrates but of fats and proteins as well Glycosuria and Ketonuria, associated with Hyperglycæmia point to an effection of the Islets of Langerhans Blood sugar above 0 18 or 0 2 per cent denotes hyperglycæmia, and mild cases of diabetes have a blood sugar level of 0 3 per cent or 0.4 per cent The highest level I have come across is 0 7 per cent Ketone bodies, namely, β-oxybutyric acid, aceto-acetic acid and acetone point to incomplete metabolism of fats. Proteins also are incompletely metabolized as in later stages of diabetes, sugar is derived from proteins.

The glycogen of the liver is markedly reduced, although it remains in the muscles. Even after feeding excess of carbohydrate, no glycogen is stored in the liver. In addition to this, the Respiratory Quotient is very low, *i e*, 0·66, and it shows no tendency to rise when carbohydrate is fed as in the normal person. This is often interpreted as showing that the tissues have lost the power to oxidize sugar, but it is not really so, and the true explanation as Macleod states may be that oxygen is retained in diabetes partly to convert fatty acids into carbohydrate, and partly to complete the oxidation of Ketone bodies.

The discovery of Von Mering and Minkowski in 1889 that the removal of pancreas from an animal results in a condition which is practically the same as diabetes mellitus in man, gave the clue to the essential lesion in this disease These experiments proved that pancreas is necessary for carbohydrate metabolism Removal of ordinary gland acini does not produce glycosuria, and it is now well established that the Islets of Langerhans are responsible for the production of an internal secretion *Insulin*, which is essential for carbohydrate and general metabolism, and absence of which produces diabetes. Attempts have been made to look for macroscopical and microscopical changes in the islets in diabetes, but without much success In most cases no structural changes are evident, although in some hydropic degeneration in the islet cells has been detected. It may be that some functional disturbance has occurred without causing any marked visible structural changes.

By special methods of staining, Lane has found that the islets contain two types of cells, namely, α and β cells, according to the type of granules in them Sections fixed by alcohol and stained with neutral gentian show a small number of cells containing granules. These are known as α–cells. Sections fixed with chrome sublimate solution, containing potassium bichromate and mercuric chloride, and stained with neutral gentian show a large number of cells containing granules, known as β-cells. In diabetes only the β-cells undergo degeneration while the α-cells persist in their original form. The extent of degeneration of β-cells depends on the intensity of diabetes. The β-cells suffer if their function is overstrained by diets in excess of the weakened assimilative power. There is also evidence that recovery from degeneration might take place by the use of proper diet provided the degeneration has not become extreme

The hormone produced by the islets, Insulin, when injected subcutaneously or intravenously produces a fall of blood sugar in the normal person In the diabetic too, it reduces blood sugar and glycosuria, and raises the Respiratory Quotient and causes the ketone bodies to disappear. We may therefore briefly say, that Diabetes Mellitus is a condition which is due to the deficiency of Insulin in the body.

It is not quite certain how Insulin acts in Diabetes There is evidence that it causes the glycogen to be formed and it diminishes gluconeogenesis. Both these processes are interrelated As I have already mentioned, formation of glycogen in the liver is an essential intermediate process in the metabolism of carbohydrates. This process is very much diminished in diabetes, but formation of glycogen in muscles still continues. Insulin corrects this. It also causes increased combustion of carbohydrates in the body I do not propose to enter into a detailed consideration of the conflicting evidence with regard to the mode of action of Insulin. Suffice it to say that "there is no stage in carbohydrate metabolism, up to that in which Lactic Acid is formed out of muscle glycogen, that this hormone does not effect. It inhibits gluconeogenesis and stimulates glycogen formation in the liver in the diabetic animals, whereas it retards glycogen formation in this organ in normal ones, except as a late effect when the animal is fasting. Under all conditions, both in normal and diabetic animals, it causes more carbohydrates to be oxidized, this being more marked in the diabetic animal, but so slight as to be imperceptible in normal ones, in which absorption of carbohydrate from the alimentary canal is proceeding. The net effect of all these changes is to lower the percentage of sugar in the blood. . ." (MACLEOD)

There is still a good deal of mystery surrounding this question. In all probability, some unknown intermediate substance is formed in carbohydrate metabolism during the course of action by Insulin, which will furnish the necessary explanation.

Lastly, I might add that we are still in the dark as to the true cause of diabetes. Although there is some evidence that excessive carbohydrate diet might affect the β-cells of the Islets of Langerhans, we are totally ignorant of factors which primarily affect them and produce those acute forms of disease as met with in early life. Various hypotheses have been put forward, namely, inflammation due to infection spreading from the duodenum up the pancreatic duct into the pancreas, thus reaching the islets *via* the acini, changes in H-ion concentration of the blood due to dyspepsia or other gastro-intestinal derangements have also been blamed But we do not know the real cause.

Methods of Diagnosis —Apart from a complete qualitative and quantitative examination of the urine for sugar and acetone bodies, the most important procedure to be carried out in a case of glycosuria is to estimate blood sugar and to carry out the sugar tolerance test, as described already. By this method we are able to differentiate between true diabetes and renal glycosuria and can ascertain the severity of diabetes if it exists It is also a valuable aid in judging the course of treatment.

Other aids to diagnosis are —

1 To determine the Respiratory Quotient.

2. To determine the alkali reserve of the blood.

I do not propose, however to enter into a consideration of these

I give below an account of some of the cases of Diabetes Mellitus at the Sir J. J Hospital, Bombay, on whom the Sugar Tolerance Test was carried out.

CASE RECORDS OF DIABETES MELLITUS—SIR J J HOSPITAL, BOMBAY.

1. A. K. G. Aged 22. Mohammedan. Hotel servant.

			Per cent
Blood Sugar	Fasting Level		0 216
Do	Half hour after 50 grms. Glucose		0 246
Do	One	do	0 256
Do	One and a half	do.	0 246
Do	Two	do	0 236

Urine—Sugar present 4.5 per cent. Acetone present.

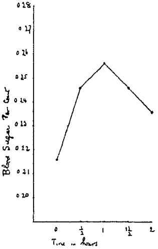


Fig. 21.

A. K G Diabetes Mellitus.

2. L K. L. Aged 28. Mohammedan. Peon.

			Per cent.
Blood Sugar	Fasting Level		0 176
Do.	Half hour after 50 grms Glucose		0.222
Do	One	do.	0 236
Do	One and a half hour	do.	0.242
Do.	Two	do	0.246

Urine.—Sugar present 7.1 per cent. No acetone or diacetic acid.

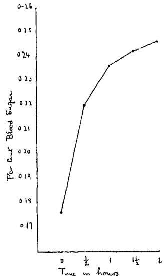


Fig. 22.

L, K, *L.* : **Diabetes Mellitus.**

3. V. M. H. Aged 35. Mohammedan Hawker.

			Per cent.
Blood Sugar	Fasting Level	..	0.207
Do	Half hour after 50 grms Glucose		0.296
Do.	One	do	0.336
Do.	One and a half	do	0.301
Do.	Two	do	0.263

Urine.—Sugar present 2.5 per cent. No acetone or diacetic acid.

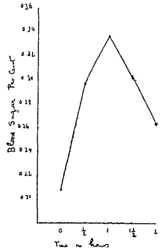


Fig. 23.

V. M. H. . Diabetes Mellitus.

1. H. K. B. Aged 30 Mohammedan.

			Per cent
Blood Sugar	Fasting Level		0.36
Do.	Half hour after 50 grms Glucose		0.444
Do	One	do	0.508
Do	One and a half	do	0.421
Do.	Two	do	0.406

Urine.—Sugar present 5.06 per cent No acetone or diacetic acid.

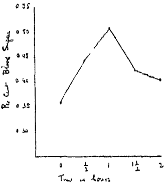


Fig. 24.

H. K. B., Diabetes Mellitus.

5. V. T. D. Aged 30. Hindu Clerk

			Per cent
Blood Sugar	Fasting Level		0 10
Do	Half hour after 50 grms Glucose		0 208
Do	One	do	0 208
Do.	One and a half	do	0 182
Do	Two	do.	0 157

Urine.—Sugar present, a trace only No acetone or di acetic acid.

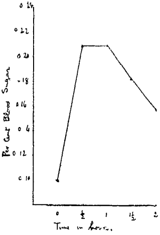


Fig. 25.

V. T. D. Diabetes Mellitus

6. C. B. Aged 30. Hindu. Farmer.

			Per cent.
Blood Sugar	Fasting Level		0.246
Do.	Half hour after 50 grms Glucose		0 271
Do.	One	do	0 291
Do.	One and a half	do	0.267
Do	Two	do	0.256

Urine.—Sugar present 7.54 per cent. A trace of acetone present.

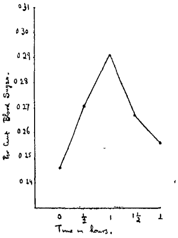


Fig. 26.

C. B Diabetes Mellitus.

7. H. A R. Aged 30. Mohammedan. Milkman.

			Per cent
Blood Sugar	Fasting Level	. . . .	. . 0.262
Do	Half hour after 50 grms. Glucose		0 286
Do	One	do.	. . 0 286
Do	One and a half	do .	. 0 280
Do	Two	do	0.276

Urine.—Sugar present 4.5 per cent No acetone or diacetic acid.

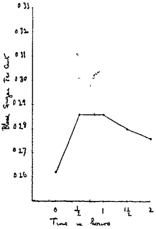


Fig. 27.

H, A R, · Diabetes Mellitus

8 B. R. Aged 25. Hindu. Policeman.

			Per cent
Blood Sugar	Fasting Level		0 201
Do	Half hour after 50 grms Glucose		0 231
Do.	One	do	0.251
Do	One and a half	do	0 251
Do	Two	do	.. ..

Urine.—Sugar present 6.5 per cent. No acetone or diacetic acid

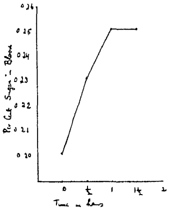


Fig. 28.

B. R. · Diabetes Mellitus

9. S. D Aged 20 Mohammedan.

			Per cent
Blood Sugar	Fasting Level		0 206
Do	Half hour after 50 grms Glucose		0 298
Do	One	do	0 306
Do	One and a half	do	0.246
Do	Two	do	0 212

Urine—Sugar present 5 per cent No acetone or diacetic acid.

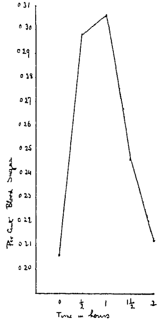


Fig. 29.

S. D. · Diabetes Mellitus.

10. A. M. Aged 40.

			Per cent
Blood Sugar	Fasting Level		0.227
Do.	Half hour after 50 grms Glucose		0.236
Do	One	do	0.252
Do	One and a half	do	0.246
Do	Two	do	0.246

Urine.—Sugar present 2.5 per cent No acetone or di acetic acid.

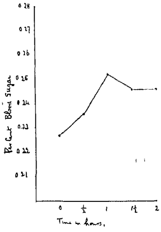


Fig. 30.

A. M Diabetes Mellitus.

11. D. M. Aged 23

			Per cent
Blood Sugar	Fasting Level		0.224
Do	Half hour after 50 grms Glucose		0.313
Do	One	do.	0.33
Do.	One and a half	do	0.307
Do	Two	do	0.307

Urine.—Sugar present 1.5 per cent. No acetone or diacetic acid.

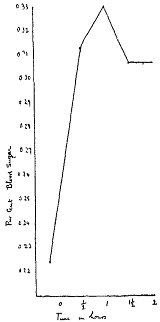


Fig. 31.

D. M. Diabetes Mellitus.

12. MISS M. M. Aged 30

			Per cent.
Blood Sugar	Fasting Level		0 207
Do	Half hour after 50 gms Glucose		0 313
Do	One	do	0 38
Do	One and a half	do	0 34
Do	Two	do	0 256

Urine.—Sugar present 6.2 per cent No acetone or diacetic acid

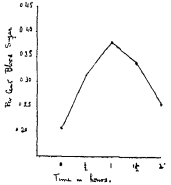


Fig. 32.

Miss M. M Diabetes Mellitus

The following is a case of *Renal Glycosuria* :—

K. S. Aged 35. Hindu.

			Per cent
Blood Sugar	Fasting Level		0.120
Do.	Half hour after 50 grms. Glucose		0.122
Do	One	do.	0 124
Do	One and a half	do	0 148
Do	Two	do	..

Urine.—Sugar present 1.5 per cent. No acetone or diacetic acid

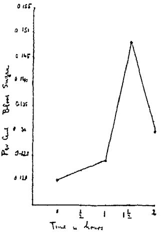


Fig. 33.

K S Renal Glycosuria.

Treatment of Diabetes Mellitus.—It is not my intention here to deal with the treatment of diabetes in any detail, but certain general principles may be stated.

In the case of diabetes in the middle-aged, a chronic and mild affection, the common variety in India, the main indication is to restrict the diet Any tendency to obesity should be corrected and if the patient is over-weight, his weight should be reduced to normal limits. The diabetic should live on a lower diet than the normal person. His calorie requirement is more in the neighbourhood of 2,000 to 2,300 per day The amount of carbohydrate should be restricted. Fasting yields excellent results. If starvation is carried out on proper lines, blood sugar is lowered and glycosuria disappears. Then by a gradual increment of the amount by the 'Ladder' system a diet is reached which supplies the body with the necessary calories and the urine remains sugar free. In this connection, I may mention that the scheme of dieting suggested by Maclean is very practical and may be adopted.

In addition to dietetic restriction, Insulin may be necessary if there is any exacerbation of the symptoms. It is particularly so if the blood sugar is high, ketone bodies are present in the urine, or if there be any septic infection. Such cases when suffering from carbuncles, boils, influenza, gangrene, etc, should be treated with Insulin.

In the acute type of case in the young, the treatment from the very start should consist of administration of Insulin Regulation of diet also, of course, is necessary. Here the rôle of Insulin is very much like that of Thyroid in the treatment of Cretinism or myxoedema

Soon after Insulin came out, some observers in India found, that it deteriorated in quality in the hot climate in this country. I carried out some experiments in my laboratory in December 1923 and January 1924 to ascertain this.

The record of one such experiment is as follows :—

A rabbit weighing 2 115 kilograms was taken and was starved for 15 hours. Its fasting level of blood sugar was

0.131 per cent. One quarter (¼) c c. or 5 units of Insulin was injected and the blood sugar was estimated afterwards

			Per cent.
Half an hour after Insulin, the blood sugar was			0.106
One hour	do.	do	0.0685
Two hours	do	do	0.067

There was no evidence of convulsions.

The samples of Insulin now on the market are quite potent, and the results of treatment are very satisfactory.

Before deciding on Insulin treatment, the first thing to make sure is that the case is not one of Renal Glycosuria This constitutes a definite contra-indication The Sugar Tolerance Test helps in settling this point.

Other contra-indications are Angina Pectoris and marked cardiac degeneration.

In the elderly patient, the principle laid down by Maclean is to begin with small doses of Insulin and to increase the amount gradually until glycosuria disappears. It is advisable to begin with 5 units twice a day and gradually work up to 30 units twice a day by the end of the month. After surgical operations, the dosage required may be greater It is given twice a day by injection about half an hour or so before the morning and evening meal.

In diabetic coma our only chance of saving the patient is to give Insulin. 20 to 30 units of Insulin should be given straightaway and the dose repeated until the condition improves Blood sugar estimations should be carried out at the same time. So long as blood sugar level is above 0.15 per cent Insulin can be safely repeated. If there is a tendency for it to fall below this level, sugar may be administered

The danger of Insulin treatment is the onset of Hypoglycæmia. Its symptoms are flushing of the face, sweating, pallor sense of constriction about the throat and chest, giddiness, marked physical weakness, coldness of limbs, inco-ordination of movements, tremor, often ending in coma and death The convulsions, which are often seen in rabbits when the blood sugar is 0.045 per cent or less, are not seen in man. This condition, which indicates over-dosage of Insulin, is readily amenable to treatment. Insulin should be stopped. Sugar should be given by mouth, either in the form of barley sugar or glucose, orange juice, etc In an unconscious patient glucose may be given intravenously. Injection of 1 c c. of 1 in a 1,000 solution of adrenalin or pituitrin 1 c c. is a great help. The patient recovers readily If Insulin is given carefully, there is no reason why hypoglycæmia should occur.

A large number of drugs, apart from Insulin, are advertised in the market for the treatment of diabetes, but none of them is of any use, with the exception of synthalin. Its only advantage is that it can be given by mouth, but it causes a great deal of gastro-intestinal disturbances, and its administration at the present stage at any rate is not to be recommended.

Hitherto the main line of treatment of diabetes has been dietetic Its only merit is that it has seldom been consistently carried out by the diabetics for any length of time With the introduction of Insulin, while a certain amount of dietetic restriction is of course necessary, the patient can live a life of ease and comfort without too much abstinence, for the dose of Insulin can be regulated according to the carbohydrate in-take. It may be useful to remember that 1 unit of Insulin can deal with about 2 grms. of glucose.

Prophylaxis—The prevention of any disease can be effectively carried out only if its cause is definitely known. While we are still ignorant of the true cause of diabetes, we know sufficiently about a few facts in its etiology to guide us to take some measures for its prevention. This is especially so in regard to the disease in the middle-aged and the old, which is so common in India Moderation in diet, especially in carbohydrates, active habits of life involving sufficient physical exercise and a placid temperament, Osler's 'Aequanimitas', are matters worthy of most careful attention by all concerned. We in the medical profession who are concerned with the welfare of the individual and the race should do all we can to inculcate these principles, and thus mitigate to some extent at least, the havoc wrought by Diabetes in this country.

In conclusion I wish to thank you all for the patient hearing you have given. I am particularly thankful to Sir B. N. Seal, the great savant and the finest type of Indian Scholar, who presides over the destinies of the University of Mysore, by whose courtesy I was able to come here and have the privilege of addressing you. To Dr. A. Subba Rao, the distinguished Professor of Physiology in the Medical College here, with whom the idea of these lectures originated, I owe a special debt of gratitude. I would also wish to thank Dr. B. K. Narayan Rao and Dr. S. Subba Rao and all others who have shown every kindness and hospitality and made my stay in Bangalore most enjoyable.

The prevalence of diabetes in India constitutes a very important Medical problem, and if by these lectures, I have succeeded in arousing interest in it, so that some more workers may enter the field and do their bit to solve the problems which are still shrouded in mystery, my object will be served.

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CONTRIBUTIONS TO OUR KNOWLEDGE OF THE ANATOMY OF THE LEMUROIDEA.

IV. THE VERTEBRAL COLUMN AND THE APPENDICULAR SKELETON OF LORIS LYDEKKERIANUS.

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INTRODUCTION.

In a previous communication (1) an account of the skull of Loris lydekkerianus was given, wherein the affinities of this lemur to the Insectivore on the one hand, and its progressive Anthropoid features on the other were pointed out. The influence of the assumption of the semi-erect posture by this animal formed the subject of discussion in the paper on the Arterial System (2). The present investigation deals with the vertebral column and the appendicular skeleton, with some reference to the modifications incidental to the arboreal habitat of the animal. The description is based on an examination of the skeletons of adult animals, both male and female. The references to the descriptions of bones of animals, other than those of Loris lydekkerianus are taken from the classical paper of Mivart (3) and the splendid monograph of Gregory (4) The papers of Woollard (5), Le Gros Clark (6) and the monograph of Wood Jones (7) have been of great assistance in the preparation of this paper.

We are greatly indebted to Professors R. Gopala Aiyer, S. G. M Ramanujam of Presidency College, Madras and C R. Narayana Rao of Central College, Bangalore, for help with literature Our thanks are due to Mr R S Aiengar and Mr G. Shankar for the X-ray photographs and Mr. K Somasundaram for some assistance in the preparation of a few diagrams.

GENERAL DESCRIPTION OF THE VERTEBRAL COLUMN.

The vertebral column consists of a series of small bones held together by ligaments; and it forms not only the support of the trunk but also gives the trunk its normal shape and protects the spinal cord with its membranes. It is situated on the dorsum of the trunk in the middle line, and measures on an average 169 mm On an examination of the column, it is found that its constituent segments or regions measure as follows .—

				mm.
Cervical region	. 7	vertebræ.		15
Thoracic region	. 14 or 15	,,		53
Lumbar region	. 9 or 8	,,		62
Sacral region	.. 4	,,	(fused)	19.5
Coccyx	. 5 or 6	,,		19.5

Before describing the characteristics of the individual vertebræ of the various segments noted above, an account of the vertebral column as a whole is considered necessary

The ventral surface of the vertebral column is made up of the centra of the various vertebræ Even a glance at it will reveal that the centra increase in length from the cervical to the lumbar series, while it is true that they enlarge in size in the manner noted above, it is to be stated that the enlargement is apparent only in the lower thoracic and lumbar regions. From the sacrum there is a rapid diminution, in the size of the centrum, to the tip of the coccyx.

The dorsum of the vertebral column is characterized by the prominent spinous processes of the vertebræ In the living animal these processes can be felt as projections if a finger is run along the back in the mid-dorsal line, the second and the seventh are the only two cervical vertebræ that possess well-formed spinous processes. There is, however, a gradual increase in the size of the spinous processes, from the third cervical which has a very sharp and short spine, to the seventh cervical which bears a large-sized spine. In the thoracic region the spinous processes attain considerable size, the anterior four project vertically upwards, whilst the others slant caudalwards until at last they overlap to produce the characteristic tile-like arrangement. The spinous processes of the thoracic vertebræ are rectangular plates; and although the first three or four of the series are nearly twice as long as broad, they gradually become broader up to the twelfth.

The spinous processes of the thirteenth and fourteenth vertebræ are peculiar in that their breadth is greater than their length The spinous processes of the lumbar vertebræ have undergone remarkable changes and are ridge-like, further the free borders of the processes are flattened out to produce incurved lips, one on either side

The sacral spines, which are more or less triangular in shape, are prominent and separated from each other. The first vertebra of the coccyx has a rudimentary spine which in others is conspicuous by its absence

On either side of the line of spines is a gutter, the "Vertebral groove" which runs the entire length of the vertebral column In the cervical and lumbar regions the vertebral groove is flanked laterally by the articular processes, but in the thoracic region the lateral wall is formed by the transverse processes, whilst the articular processes form the floor of the groove The vertebral groove which is broadest in the cervical region and in the region of the first thoracic vertebra, becomes narrowed as the lumbar region is reached In the lumbar region though the groove is narrowest its capacity is increased by the incurved lipping of the lumbar spines. In the last portion of the lumbar and in the beginning of the sacral region, the gutter which is flanked by the Iliac bones is deep It should be noted that the gutter is interrupted in this part as the articular processes form but deficient lateral walls. The vertebral groove is absent in the coccygeal region. In this groove are lodged the deep and intermediate layers of the post-vertebral muscles. Looking at the dorsum of the vertebral column, one is impressed at the continuity of the bony surface completely encasing the spinal cord The imbricated laminæ and the spines produce this effect all along the column except in the last lumbar interval

The lateral aspect of the vertebral column presents in the cervical region a narrow sulcus which is formed by the transverse and articular processes. The sulcus which occupies a relatively ventral plane ends at the first rib In the thoracic region there is no such sulcus as this interval is filled in by the vertebral ends of the ribs. On removal of the ribs, the facets for the heads of the ribs on the centra and those for the tubercles of the ribs on the transverse processes become visible In the lumbar region again the sulcus becomes manifest. Here, as in the cervical region, it is formed by the transverse and articular processes. The border formed by the transverse processes which do not meet end to end, is deficient.

The intervertebral foramina are situated between the contiguous borders of the pedicles of the vertebræ In the cervical region they are very narrow slits placed almost on a level with the centra, and in the thoracic region they are situated in a more dorsal plane, bigger in size and are visible at the angle between the posterior margin of the rib, and the body of the vertebra. The foramen is formed by the pedicles In the lumbar region the foramen is placed in a still more dorsal plane than that in the thoracic segment, a condition brought about by the very prominent centra and the wing-like articular processes. The foramen is almost oval in this region and is flanked in its cranial part by the posterior margin of the pedicle, a small portion of the lateral surface of the body and the ventral margin of the mammilary process (metapophysis) The caudal part is formed by the anterior margin of the pedicle, the accessory process (anapophysis), and a small area of the centrum. An examination of the intervertebral foramina brings out the fact that towards the cranial part the major portion of the foramen is formed by the anterior of the two vertebræ and that as we approach the pelvis the share of the posterior of the two vertebræ is increased, the contribution of the anterior of the two vertebræ always being greater.

The Vertebral canal which is formed by the bodies, pedicles and the laminæ of the various Vertebræ follows the curves of the column to be described immediately. The canal is transversely oval in the cervical region, ovalish in the thoracic and almost circular in the remaining portion. It terminates generally at the caudal end of the sacrum though at times it extends into the length of the first coccygeal vertebra.

THE CURVES OF THE VERTEBRAL COLUMN.

The presence of curves is a striking character of the vertebral column. Piersol (8) while dealing with the curves of the vertebral column of the human subject, states that "the curve of the spine is necessarily an arbitrary one since it varies not only in individuals and according to age, sex and occupation but also on the time of the day and the posture; being longer when lying than when standing and after a night's rest than a day's work." With limitations depending upon the habits, posture, age, sex, etc., of the animal (Loris lydekkerianus) the vertebral column exhibits variations in the curvatures. Nevertheless the column presents a series of curves in what might be called its natural normal posture which has to be explained on the mechanics of the stress and strain which it is subjected to. Accordingly Loris lydekkerianus can be said to possess the cervical, the thoracic, the lumbar and the sacro-coccygeal curves (Text Fig. 1). In Loris lydekkerianus as in most

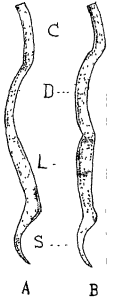

Fig. 1.

Diagrammatic representation of the curves of the vertebral column. A—Man, B—Loris lydekkerianus, C—cervical, D—Thoracic, L—Lumbar, S—Sacral.

other primates the cervical curve is never a consolidated one, since it is altered or obliterated on a change of position of the head In the sagittal plane the cervical is convex forward; the thoracic, the lumbar and the pelvic curves are concave forward In the prono-grade mammals there is a single curve, between the thoracic and lumbar regions, but in these animals the thoracic curve has a constant shape inasmuch as it is the persisting primary curve of the embryonic axis The cervical curve, on the other hand, is an attempt to raise the head from the thorax. The "lumbar curve" is in this animal concave forward though not continuous with the thoracic curve. Indeed the thoracic curve is a segment of a circle with a shorter radius The lumbar curve is relatively more flattened and a dimple can be *felt* at the thoraco-lumbar junction demarcating the two curves. We know that this animal generally assumes a semi-erect posture, if it had assumed an *erect posture* there would have resulted a lumbar convexity, and if it were just like other quadrupeds there would not have been two curvatures between the neck and pelvis. It may therefore be suggested that the production of a separate lumbar curve is the result of the assumption for the major part of the day of a semi-erect posture and that it occurs after birth. We have however not examined the vertebral columns of late intra-uterine embryos and of new-born or even of very young specimens The intervertebral discs play a minor part in the production of the vertebral curves They act as buffers between the individual vertebræ giving a certain amount of elasticity to the column as a whole.

THE MOBILITY OF THE VERTEBRAL COLUMN.

In any attempt to analyse the movements of the vertebral column we have to bear in mind the fact that "the more massive the vertebral centra, the lesser (would be) the mobility of the vertebra" The truth of the above statement becomes obvious when it is realized that the sacrum which is formed by the fusion of several vertebræ does not move at all The coccyx which forms part of the framework of the pelvis does not take part in the movements of the column. In the cervical region the vertebræ are small and allow of a great latitude of movements in several planes In the thoracic region where movement is inferior only to that of the cervical region, the centra are of medium size and allow a fair range of movements In the lumbar region, however, a very different condition obtains. The centra are nearly three times as long as those of the thoracic vertebrae and appear to form a series of immovable joints allowing of no intervertebral movements at all.

Further, except that of the last which is upright, the neural spines of the thoracic vertebræ are retroverted ; thus the 'anticlinal' vertebra which is situated in Loris lydekkerianus near the end of the thoracic rib-bearing series forms the region of centre of motion If the animal is observed in its normal posture (at rest) it is seen that the lumbar region is nearly straight, and that the thoracic portion of the column is bent about the centre of motion referred to above The upright neural spines of the lumbar region strengthens the statement that there is no movement of the lumbar region According to Thompson (9) "the length and inclination of the spines are proofs that the region at which they are long and strong is the one that bears the greater weight and the one that has to perform greater bending movements" Thus taking the inclination of the spines into consideration, we find that in Loris lydekkerianus the greater strain during bending movements is borne by the posterior thoracic vertebræ, and that the weight is transmitted to the ground, when the animal walks on all fours, by the anterior thoracic region. If the animal is watched while it is walking, it is seen that the weight is thrown on the front limbs The hind limbs appear to be passive ; the heels do not touch the ground. The hip and the knee joints seem to be semi-flexed ; and the posterior half of the body lumbers along.

Professor Wood Jones, while discussing the spinous processes of the vertebral column, states: "Great interest centres round the Lemurs in the study of the disposition of the spinous processes. In this feature the majority of them follow the Tree Shrews, and those that are characterized by special activity present a remarkably double-sloped series of spines" But in the more active 'arboreal jumpers' like Tarsius and Galago the forward slope of the lumbar spines is particularly acute But with some other Lemurs the most puzzling feature of the problem is introduced, for Nycticebus, as a type of the Asiatic Slow Lemurs, presents a series of spines as uniformly retroverted as that seen in the Sloths themselves " The similarity between the vertebral spines of Nycticebus, and those of the Sloths is regarded by Wood Jones as a case of convergence. And again Wood Jones states that ' the case of the Slow Lemurs is all the more interesting since the absence of a dorso-lumbar centre of movement and the presence of a practically uniform series of spines are seen in another group of arboreal primates."

The similarity of the neural spine series in Nycticebus, Edentates and some Anthropoidea is attributed to the arboreal habits of the animals It is important to observe here that *Loris lydekkerianus* which is no less arboreal than the animals referred to above possesses a vertebral column in which the anterior thoracic neural spines are retroverted, and the last thoracic vertebra bears an upright spine, a feature which it shares with the lumbar vertebræ This difference is probably due to the fact that in Loris lydekkerianus the vertebral column does not act as a whole, the anterior thoracic vertebral segment bends like a spring on the centre of motion.

THE VERTEBRAE.

The vertebræ possess some common features which undergo modifications according to the regions in which they occur. The first and the second cervical vertebræ, the sacrum and the coccyx undergo very marked alterations.

A typical vertebra consists of a body or centrum, from the dorso-lateral angles of which a pair of pedicles spring. The pedicles support a pair of laminæ which meet in the mid-dorsal line to form the spinal canal (vertebral foramen). From the sides of the arch, at the junction of the pedicles and laminæ project the transverse processes The articular surfaces (Anterior and Posterior Zygopophyses) are situated at or near the lamino-pedicular junction. At the junction of the two laminæ the spinous process projects

The centrum is cylindrical with rough anterior and posterior surfaces which articulate with the intervertebral fibro-cartilages. The dorsal surface of the centrum is flat, quadrilateral in shape and is perforated by many vessels one of which is of considerable size. The anterior and posterior borders of contiguous pedicles contribute to the formation of the intervertebral foramina The transverse processes of the vertebræ present in the thoracic region a facet, the costal facet, with which articulates the tubercle of the corresponding rib In the cervical region the costal element of the transverse process forms the ventral wall of the 'vertebrarterial foramen' so that the transverse process is really a complex of the *true transverse element* and the *costal element*, separated by a foramen and joined by a *costo-transverse bar* In the lumbar region the transverse process proper is reduced to a very rudimentary 'mammilary' and a prominent 'accessory process' whilst the costal element forms the *transverse process* The anterior and posterior edges of the lamina of the neural arch bear flattened, nearly oval and smooth facets which are called Zygapophyses and which articulate with the corresponding facets of the vertebra in front and behind The articular facets are disposed in a systematic manner The one situated on the front edge of the arch, the pre-zygapophysis, is directed dorso-medially whilst that on the posterior edge, the post-zygapophysis, is directed ventro-laterally

The spinal canal (vertebral foramen) is bounded ventrally by the dorsal surface of the centrum, the fibro-cartilage and the dorsal longitudinal ligament, and dorsally and on the sides by the laminæ, the ligamenta flava and the pedicles The canal lodges in addition to the spinal cord, the membranes of the cord, the spinal nerve roots the vessels supplying the vertebræ and a varying quantity of adipose tissue.

The Cervical Vertebrae.

The first cervical vertebra also known as the *Atlas* (Text Fig. 2) supports the globe of the head It has no centrum and is devoid of the spinous process. The bone is ring-shaped

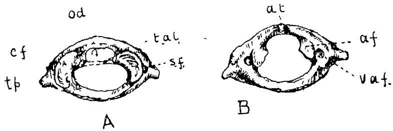

Fig. 2.

Diagram of Atlas. A—Anterior view, od —position of odontoid; tal.—transverse atlantic ligament, cf —condyloid facet; tp —transverse process, sf —suboccipital foramen, B—Posterior view, at—anterior tubercle, af—articular facet, vaf.—vertebrarterial foramen.

and consists of a ventral and dorsal arch and two lateral masses. The ventral arch contributes a fifth and the dorsal arch two-fifths of the ring Some fibres of longus colli muscle get attached to the ' anterior tubercle ' situated in the centre of the convex ventral arch. The inner surface of the ventral arch possesses an oval facet for the odontoid process The dorsal arch has a very rudimentary tubercle to which the Recti capitis muscles are attached. On either side is the foramen which transmits a muscular branch from the intra-osseous part of the vertebral artery The lateral masses support the weight of the head when in the semi-erect posture. Each of the lateral masses, it is to be noted, contributes a fifth of the ring. The cotylus or the condyloid facet which is borne on the anterior aspect of the lateral mass articulates with the condyle of the occiput. The auricular cup-shaped facets, one on either of the lateral masses, approach each other dorsally and diverge ventrally. They are, however, not so very divergent as in Macacus, or Lemur mongoz and appear to be more like those of Notharctus. Projecting from the inner margins of these facets, nearer the ventral margin are two tubercles which serve for the attachment of the transverse atlantic ligament The latter divides the ring of the atlas into two unequal compartments, the ventral of which helps to keep steady the odontoid and the dorsal one lodges the spinal cord. The posterior Zygapophyses are rounded, directed medially, posteriorly and slightly dorsally They are slightly concave and articulate with the pre-zygapophyses of the axis. The transverse processes are farther apart than in any other vertebra, and the costal and transverse elements are fused to form a single tubercle It is interesting to note that in Cebus the transverse processes are turned ventralward indicating short longus colli muscles but in Loris lydekkerianus they are directed antero-posteriorly as in Notharctus and L mongoz The transverse process bridges over the 'foramen transversarium' as in L mongoz, Cebus and Macacus and in this respect L. lydekkerianus differs from Notharctus in which it does not bridge over the 'foramen transversarium'.

The 'foramen transversarium' is at the base of the transverse process and runs first anteriorly and then turns almost at right angles to run an intra-osseous course to open at the retreating angle between the lamina and the condyloid surface During the intra-osseous course the artery gives off an anastomatic branch which comes out through the foramen already referred to The sub-occipital nerve after it leaves the spinal cord runs alongside of the artery in its intra-osseous course to emerge on the anterior aspect of the transverse process at its base. It is to be stated here that the artery and the nerve diverge at almost a right angle. The comparatively larger size of the opening for the spinal cord, the disposition of the sub-occipital nerve and the vertebral artery, are in harmony with the progressive nature of Loris lydekkerianus, and it also suggests that the animal under study is in advance of Notharctus and that though it has several characteristics in common, its rank is lower than that of Macacus and Cebus

The axis (Text Fig 3) is easily identified by its odontoid process which projects forward from the centrum and round which the atlas carrying the head rotates. Seen from behind the axis is unlike the other cervical vertebræ since all its individual parts are massive each to each in comparison with those of the others. The spinous process and the transverse

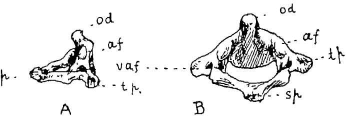

Fig. 3.

Diagram of Axis. A—Lateral view, od.—odontoid process, af —articular facet, v af —vertebrarterial foramen, tp.—transverse process, sp.—spine; B—Dorsal view (slightly tilted), Lettering as in A.

processes of the other cervical vertebræ are much shorter. The centrum of the axis presents a marked hypapophysial ridge as in Cebus The extension posteriorly of the base of the ventral surface of the centrum contributes to the formation of the convexity, ventrally of the cervical segment.

The odontoid process is a strong conical process with a globular extremity It is smaller than in the carnivores At its junction with the centrum is a constriction, the neck On its ventral aspect, a short distance from its free end is a fairly big, round convex facet for articulation with the ventral arch of the atlas. On its dorsal aspect is a groove for the transverse atlantic ligament In addition there is a ridge in the median line on either side of which the alar ligaments get attached. The pedicles and the laminæ together form four-fifths of the almost circular, comparatively large neural canal The transverse processes are divergent as in Notharctus (Gregory), and they are proportionately massive, winglike and do not resemble those of Cebus or Macacus except in some minor characteristics. The true transverse elements are attached to the centrum, but the costal elements arise from the pedicles and enclose the vertebrarterial foramen which is quite big The tip of the transverse process is not bifid. The spinous process is the most prominent of the cervical series It ends in an extensive knoblike extremity with rough depressions for the attachment of ligaments and the muscles of the back of the neck. The pre-zygapophyses are situated on the body as they transmit the weight of the head directly to the axis, and they are directed antero-laterally and articulate with the atlas. The post-zygapophyses are much smaller. The pre-vertebral notch which is well marked and deep, lodges the vertebral artery. The nerve lies behind the artery in this situation. The post-vertebral notch which is also well marked contributes to the formation of the inter-vertebral foramen for the spinal nerve roots.

The following features of the axis indicate that Loris lydekkerianus belongs to a progressive type :—

(*a*) The strong, if not massive, odontoid process.
(*b*) The pronounced median hypapophysial ridge.
(*c*) The posteriorly produced median ventral surface.
(*d*) The alar termination of the transverse processes.

General Characteristics of the Cervical Vertebra (Text Fig. 4.)

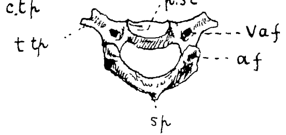

Fig. 4.

Diagram of a cervical vertebra (Posterior view) p.sc —posterior surface of centrum, c tp —costal element of the transverse process, t.tp —transverse element of the transverse process. (Costo-transverse bar is shown by shaded portion between c tp. and t.tp.) v.af.—vertebrarterial foramen, af —articular facet, sp.—spine.

The centrum is small and flattened dorso-ventrally. The surfaces slope in such a manner that their ventral margins are on a more posterior level than their dorsal margins. The costal element arises from the angles of the centrum whilst the transverse elements spring from the pedicles. The enclosed foramen transversarium is apposed to the body The costal and transverse elements are horizontal plates of bone placed one behind the other, and the costo-transverse plate is so formed as to produce a hollow sulcus in which lies the spinal nerve root The nerve lies behind the vertebral artery The costo-transverse bar is deficient and is bifid at the free end, the more dorsal of the bifid ends is the longer and is produced to a greater extent dorsally than the anterior ventrally The costal element, as it joins the body, produces an anterior lipping of the anterior surface of the centrum. Into the concave surface thus formed the posterior projecting surface of the next bone is received. The articular facets are at the lamino-pedicular junction The anterior facet (pre-zygapophysis) is inclined to the median line whilst the posterior one (post-zygapophysis) is inclined laterally. The laminæ are slender plates which contribute to form more than half of the short neural canal. The neural spines of the cervical vertebræ vary in size.

The third cervical vertebra—The spinous process of this vertebra is but a tubercle at the junction of the two laminæ *The fourth cervical vertebra* has a slightly longer spine If the third and fourth vertebræ are laid flat on a plane surface, the tips of the transverse processes and that of the neural spine of the latter come into contact with the surface but the spine of the former does not touch the surface. This is due to the varying curvatures of the arches of the laminæ. *The fifth vertebra*, except for the longer neural spine it possesses, is identical with the fourth. *The sixth cervical vertebra* generally resembles the fifth one but the groove for the cervical nerve is bigger and the spinous process assumes the character of a real spine.

The seventh cervical vertebra.—The laminæ of this vertebra are broader being nearly one and a half times as broad as that of its immediate predecessor The spinous process is the longest of the series excepting that of the axis The inclination of the spine is not so acute as those of the other cervical vertebræ but is *nearly vertical* and resembles the first thoracic neural spine.

The transverse processes which are the longest of the series, present some variations. In some specimens the vertebrarterial foramen is enclosed, in others not. Where the costo-transverse bar is present and the foramen enclosed, the tips of the costal and transverse elements are more divergent than the others. The former lies across the transverse process of the first thoracic vertebra. When there is no enclosed foramen, the transverse element is stouter and longer and at the same time the costal element of the sixth cervical vertebra which assumes greater prominence makes a definite attempt to lie across the transverse process of the first thoracic vertebra but just falls short of this condition. It should be stated that the last cervical vertebra does not articulate with the first rib, and that we have not come across any specimen with cervical ribs.

Thoracic Vertebrae—General Description.

The total number of thoraco-lumbar vertebræ is 23 of which 14 or 15 constitute the thoracic vertebræ. The vertebræ of this region increase in size cranio-caudally though imperceptibly. The facets on the ventro-lateral angles of the vertebral centra for the heads of the ribs form a distinguishing feature of the series. Further the transverse processes of all but the last two thoracic vertebræ bear on their ventral aspect articular facets for the tubercles of the ribs. The body of each vertebra articulates with two pairs of ribs—the pair with which the vertebra numerically corresponds and the one next to it. It is to be noted that as in Notharctus, the anterior articular surface does not make an angle with the long axis of the centrum. The centrum resembles that of L. mongoz and of Cebus in being more or less cylindrical, and differs from the transversely elongated centrum of Macacus. The ventral surface of the centrum is convex as in Cebus and not flat as in Notharctus. The thoracic transverse processes which are broad and expanded antero-posteriorly are more appressed to the sides than in the case of Notharctus, Cebus or Macacus.

A brief description of the neural spines has already been given (see page 107). The neural spines which are long are rectangular plates springing from the laminæ The disposition of the spinous processes varies in that the earlier ones are nearly vertical, and the following ones are sloping towards the pelvis The slope or the inclination becomes more and more pronounced until the typical tile-like arrangement is produced The spine of the last thoracic vertebra, however, has so altered that its breadth is greater than its length and it is directed vertically upwards.

A Typical Thoracic Vertebra (Text Fig. 5).

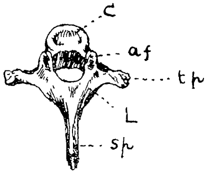

Fig. 5.

Diagram of Thoracic vertebra. (Posterior view). C—centrum; af.—articular facet, tp —transverse process, L—lamina, sp —spine.

The thoracic vertebra has a more or less cylindrical body whose antero-posterior diameter is greater than the dorso-ventral, and whose lateral diameter is greater than the dorso-ventral The flat anterior and posterior surfaces of the body are like the greater sectors of a circle The anterior surface is at right angles to the long axis of the body whilst the posterior surface is slightly inclined so that its ventral margin is on a more posterior plane Though a definite hypapophysis is not in evidence, it is easy enough to make out that the centrum is compressed laterally producing two saddle-shaped areas on either side of a mesial prominence. At the ventro-lateral angles are to be seen an anterior and a posterior pair of facets, the former of which is the larger. These facets along with those on the contiguous vertebræ and the intervening fibro-cartilages form shallow, circular sockets for the heads of the ribs The pedicles which are flattened show an anterior inclination. As they spring from near the anterior margin of the body the anterior vertebral notch is rendered shallower. The roominess of the posterior notch is impaired by an oblique bridge of bone which passes from the body to the pedicle thus creating two foramina : the small one exclusively for the vein, and the larger one for the spinal nerve root In addition, just by the side of the foramen for the vein is another minute foramen which probably is for the nutrient vessel. The laminæ which are inclined caudally lie on a more posterior plane than the posterior margin of the centrum. They are broad and overlap the laminæ of the succeeding vertebra and produce the imbricated appearance The vertebral foramen is ovalish transversely and relatively smaller than in the cervical region. The neural spine is a long, flat rectangular plate of bone and is inclined caudalwards. The free border of the spine is slightly thickened The pre-zygapophysis projects forwards directly from the junction of the pedicle and lamina. It is directed dorso-laterally. The post-zygapophysis is less prominent and is directed ventro-medially The transverse process is flat and projects laterally from the lamino-pedicular junction with a slight inclination cranialwards. Its extremity bears on its ventral aspect a fairly big-sized circular facet for the tubercle of the rib.

The first thoracic vertebra.—The anterior articular facet is complete and the first rib articulates with it The posterior facet conforms to the usual type The anterior articular facets (pre-zygapophyses) are far apart being situated on the transverse processes The anterior and posterior vertebral notches are about equal in depth There is no oblique bridge of bone dividing the intervertebral foramen. The transverse processes are pushed farther outwards by the bigger-sized pedicles

The twelfth vertebra has a larger body and resembles the lumbar vertebra. The transverse process which is thick and short possesses an articular facet for the tubercle of the thirteenth rib, and a tubercle for attachment of muscles and ligaments The posterior articular facets originate from the laminæ and are set far apart. The foramen for the vein is present

The thirteenth vertebra.—The transverse process is a tiny spicule projecting posteriorly to support the bony bridge which transmits the vein from the vertebral canal. The zygapophyses are very prominent. The pre-zygapophysis which is directed anteriorly, is bigger and bears a facet which is cup-shaped and which is directed dorsally and slightly medially. The post-zygapophysis which arises from the lamina is directed posteriorly and bears a facet which is directed ventrally and slightly laterally The transverse process does not articulate with the rib and the facets for the heads of the ribs are borne by the centrum

The fourteenth vertebra resembles the lumbar vertebra to the greatest extent The transverse process is rudimentary, there is no special foramen for the transit of the vein. Anapophyses and metapophyses are just making their appearance The disposition of the pre-, and post-zygapophyses is more or less similar to that of the thirteenth vertebra. The pre-, and post-zygapophyses meet to produce wing-like expansions and enclose foramina which lodge the veins. The facet for the fourteenth rib is just under a circle There are no posterior facets for these ribs. When there are fifteen thoracic vertebræ, the last three of the series assume the characteristics just mentioned.

The Lumbar Vertebrae.

The lumbar vertebræ are nine or eight in number so that the number of thoraco-lumbar series is always twenty-three They can be quite easily distinguished from the cervicals, and most of the thoracic vertebræ by their size The vertebrarterial foramina and the costal facets are absent

A typical lumbar vertebra (Text Fig 6).—The body of the vertebra which is nearly twice as long as broad, is cylindrical in shape though its transverse diameter is greater than

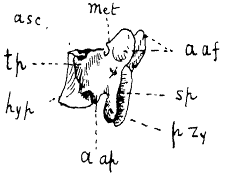

Fig. 6.

Diagram of a lumbar vertebra (Lateral view). a sc.—anterior surface of centrum, met—metapophysis, a.af.—anterior articular facet; sp.—spine, pzy—post-zygapophysis; a ap.—anapophysis; hyp.—hypapophysis, tp.—transverse process

the vertical. The ventral surface of the body is divided into two convex surfaces by a prominent hypapophysial ridge. On either side of the hypapophysis is a foramen for a vein. The foramina, however, are prominent in the more posterior centra of the series. The dorsal surface of the body is as usual rough and presents a relatively large foramen in the centre for a vein. The anterior and posterior surfaces are flat. The pedicles are flat plates arising along nearly the whole length of the dorso-lateral angles. Anteriorly the pedicle is flush with the surface. It projects dorsally with an anterior inclination, with the result that the anterior vertebral notch is inconspicuous whereas the posterior notch is rendered very deep. The laminæ are flat plates and take origin from the dorsal margins of the pedicles. They meet in the mid-dorsal line. The plates are of such a shape that they produce anteriorly a V-shaped incisura but posteriorly the united margin is more or less horizontal. It is obvious that the laminæ are placed on a more posterior plane than the body inasmuch as the body and the laminæ are of equal length. The free margins are bevelled for articulation with the contiguous vertebræ. The spinous process is a thick and prominent ridge, the free dorsal margin of which is curled into lips This renders the otherwise thin margin into a narrow surface The dorsal surface of the lamina, the sides of the spine with its incurved margin and the dorsal surface of the zygapophysis together form the boundary of the gutter referred to above (see page 103) The zygapophyses are by far the most striking parts of the lumbar vertebræ They project beyond the level of the body in all directions. Viewed from the dorsal aspect, the body is invisible except at the incisura produced by the laminæ. The pre-, and post-zygapophyses meet to form a wing-like expansion and enclose a foramen for the vein as in the fourteenth thoracic vertebra; but as we approach the sacrum the fusion is incomplete and the foramen which persists is completed by a fibrous band running across the interval between the two processes. The pre-zygapophysis has a deep concave facet directed dorso-medially The facet of the post-zygapophysis is convex and directed ventro-laterally.

In the lumbar vertebræ the costal element persists as the *transverse process* whilst the true *transverse element* is broken up into the metapophysis and anapophysis. The metapophysis which is a rudimentary tubercle flanking the anterior articular facet medially, is situated at the junction of the pedicle and the lamina. The anapophysis, on the other hand, is a fairly big triangular spicule directed caudalwards from the posterior margin of the pedicle The successive lumbar vertebræ form, in this animal, a series of more or less immovable joints and thus produce a nearly immobile consolidated lumbar column. The anapophysis and the posterior zygapophysis form a retreating angle into which the anterior zygapophysis and the rudimentary metapophysis of the succeeding vertebra are wedged. Moreover the bevelled edges of all these together with the bevelled laminæ complete the solidarity of the joints.

The transverse processes are, as noted above, the costal elements and they are rudimentary in the anterior part of the lumbar region, whilst in the posterior part of the region they gradually increase in dimension until at last in the last of the series they attain considerable proportions. These processe which ought really to be considered as arising from the ventro lateral angles of the centrum are not inclined either anteriorl or posteriorly The vertebral canal is oval and much smalle than in other regions

In the last three vertebræ the zygapophyses are discret and the gap is bridged over by a strong fibrous band whic produces the foramen for the vein as in the previous verte bræ The body of the last lumbar is actually shorter than tha of the penultimate lumbar The last lumbar takes an activ part in the formation of the pelvic girdle in some specimen and in such a case it possesses on the transverse processes an the post-zygapophyses facets with which articulates the Ileum

It is interesting to note that in leaping arboreal animal the neural spines of the lumbar vertebræ have a forward in clination because of the strong pull of the erector spinæ o them In animals which do not generally assume an erec posture the spines are also drawn forwards. This conditio obtains in Lemurs which do not assume an erect posture an which are at the same time given to leaping from branch t branch. But L lydekkerianus which is very slow in it movements, which usually assumes a semi-erect posture (excep when walking) and which we have never seen to leap in an circumstance, possesses rudimentary vertical neural spine which extend slightly posteriorly Closely correlated wit this is the weak nature of the erector spinæ , further the transverse process carries a posterior process of considerable strengt for the strong Psoas muscles which are constantly used to dra the femora forward, a feature that is common to all Lemuroidea but which in Anthropoids gradually disappears unti at last in man they become very small with practically n tension on the psoas. The rudimentary nature of the lumba spine with the associated weak erector spinæ muscles is thu the result of the peculiar habits of the animal. In other words the skeletal structures, as also the associated muscles of th lumbar region, have adapted themselves to meet the altere stress and strain

The Sacrum.

The sacrum is a compound bone formed by the fusion of four sacral vertebræ, we have followed Milne Edwards in fixing the posterior limit of the sacrum by taking "the place of insertion of the ischio-sacral ligaments" into consideration The sacrum is wedged in between the two Ilea and it can be felt in the small of the back between the upper parts of the two hips. It is held in position by strong ligaments and has the form of an inverted pyramid the apex of which is completed by the coccyx The cranial part of the truncated pyramid is broad and the caudal part is very narrow. The sacrum has a base or anterior surface, a narrow truncated apex, a rough dorsal and two lateral surfaces and it has three borders:— a ventral rounded border, and two interrupted postero-lateral borders

The base is directed forwards and slightly dorsally; its ventral portion is formed by the anterior surface of the first sacral vertebra. The neural canal is very much reduced and is nearly round. The pre-zygapophyses of the first sacral project dorsally The centre of the ventral border of the body is marked by a prominence, the promontary of the sacrum. The apex is the posterior surface of the last sacral vertebra. The dorsal surface of the sacrum is rough and presents a series of spines, which are discrete and of varied sizes The first sacral bears the largest spine whilst the second the smallest. It is not unusual to find these spines bridged across by bony trabeculæ. The zygapophyses are all fused together. On either side of the spine, corresponding to each vertebræ, is a foramen

The rounded ventral border which carries prominent hypapophyses forms part of the sacro-coccygeal curve. Beginning at the promontary it runs posteriorly and slightly dorsally up to the end of the first sacral, and it then takes a sudden dip in a more dorsal direction up to the end of the second sacral and finally curves ventrally and posteriorly to the end of the sacrum to become continuous with the coccygeal portion of the curvature

The ventro-lateral surfaces.—Here the lines of fusion of the vertebræ can be easily made out. The inter-vertebral foramina are double in those masses which take part in the formation of the hip-girdle as an anatomical necessity whilst in others of this series the foramina are normal. The foramen for the dorsal ramus lies ventral to the zygapophysis of the second sacral while that for the ventral ramus at the junction of the first and second sacral On the dorsum of the fused lateral mass is the irregularly oval, *dorso-laterally* directed 'auricular area' anterior to which is an irregular rough depression for the strong sacro-iliac ligaments "The auricular area" makes an angle of 30° with the median line

It is a well-known fact that greater the number of ankylosed sacrals, greater is the fixity and stronger the attachment of the pelvis to the vertebral column In the higher Anthropoidea there are generally five sacral vertebræ ankylosed. In the monkeys there are two or three and rarely four ankylosed. The vertebræ that actually take part in the sacro-iliac articulation are the true sacrals whilst the others are pseudo-sacrals which properly belong to the caudal series In the Anthropoidea and in monkeys the first three share in the formation of the facet, in the lemurs the first sacral mostly bears the articular surface In Loris lydekkerianus the first and the major portion of the second sacral vertebræ contribute to the sacro-iliac articulation

The contraction of the articular portion in Loris lydekkerianus is presumably associated with partial uprightness and the absence of a tail; for in the tailed forms such as Cebus and Macacus this contraction is not observed, although in the *slender tailed* Notharctus it is observable.

Variation in the Sacrum —In the sacrum of one of the specimens the last lumbar vertebra has become incorporated with the first sacral with the result that the sacrum has now two promontaries produced by the last lumbar and the first sacral vertebræ respectively. The sacrum proper appears to be deeply sunk. It is massive and consists of only four bones The crest of the ilium is at the level of the anterior border of the last lumbar. The Lorisinæ have particularly long cœlomic cavity due to the large number and the length of the individual lumbar vertebræ. The sacrum and the pelvic girdle have shifted forwards in this particular specimen and lessened the extent of the cœlomic cavity

This reduces the pre-sacral vertebræ to 29 instead of 30 which is the constant number for the species but does not tend to reduce the number of coccygeal vertebræ which here is six

The Coccyx.

The Coccyx consists usually of five individual vertebræ The first has a fair-sized spine and rudimentary articular processes which form a tunnel for the egress of the last sacral nerve The members decrease in size gradually until at last the last vertebra is but a conical piece of bone. They are all cylindrical in shape with rudimentary spines and articular processes The last coccygeal is all centrum in contrast to the first cervical which does not possess a body at all The number of coccygeal vertebræ is liable to variation, may be reduced to four or increased very rarely to six

In the following table is appended a comparative statement of measurements of the vertebral column —

Particulars	Loris lydekkerianus. mm.	Notharctus Osborni. mm	Lemur mongoz mm
Total length of Cervical Vertebræ	15	..	
Do Thoracic Vertebræ	53		..
Do. Lumbar Vertebræ	62	92	91 5
Do Sacrum	19 5		.
Do Coccyx	19.5	.	.
Total length of column	169 mm		
Atlas.—Antero-posterior diameter above vertebrarterial foramen	5	5 5	6 5
Transverse diameter	15	.	
Vertical diameter	7 5		..
Axis (C 2) Base to tip of Odontoid	6	..	
Extreme Transverse	9		..
Tip of Tr to tip of spine	9		..
C 3 Ant Zyg to Post Zyg.	3	6	5 50
C.4 Do.	3	6	5 50
C.7 Extreme Transverse	11 50		
Antero-posterior	3 5	.	..

Particulars.			Loris lydekkerianus. mm.	Notharctus Osborni. mm.	Lemur mongoz. mm.
Dorsal 1		Ant.-Post. diameter of body (*a*)	3	7 5	6
		Transverse diameter (*b*)	4	7 4	9
Dorsal 1	(*a*)		3 1	8 3	6
	(*b*)		4	7	8
Dorsal 10	(*a*)		4 1	10	8 7
	(*b*)		3 5	8 3	7 9
Dorsal 11	(*a*)		4 1	.	10
	(*b*)		3 6	.	9 5
Dorsal 14	(*a*)		4 6		
	(*b*)		5 0		..
Lumbar 1	(*a*)		5 2		12 4
	(*b*)		5		10 3
Lumbar 2.	(*a*)		5 8	13 3	13 4
	(*b*)		5	10	10 9
Lumbar 5	(*a*)		7		15 0
	(*b*)		5 8		12 0
Lumbar 7	(*a*)		7	13 5	14 3
	(*b*)		6 2	12	12 7
Lumbar 8	(*a*)		5 5		11 4
	(*b*)		5 5	..	12 0
Sacrum.	S 1	Ant. Post. diameter (*a*)	5 5	11 4	10 5
		Transverse diameter across the Process (*b*)	9 2		22 5
	S. 2	(*a*)	5		10
		(*b*)	7 8		18 2
	S 3	(*a*)	4 5	9 3	9 5
		(*b*) of centrum	2.8		8 6
	S 4	(*a*)	4 5		
		(*b*) of centrum	2.2	.	.
Coccyx	1.	(*a*)	5		.
	2.	(*a*)	4	Caudal Vertebræ	Caudal Vertebræ
	3	(*a*)	4	15	19
	4	(*a*)	4		.
	5	(*a*)	2 6		.

THE STERNUM AND THE RIBS.

The Sternum.

Like the vertebral column, the sternum which measures about 36 mm. in length is formed by a series of bones called sternebræ held together by flakes of strong fibrous tissue. It is placed in the median line on the ventral aspect of the thorax and is connected on each side to the vertebral column by the ribs and their costal cartilages. The cartilages of the anterior nine ribs articulate with the sternum directly; four or five get attachment in an indirect manner and the last of the series which is free, is known as the floating rib. It can be divided into three distinct parts for purposes of study and description. (*a*) The Pre-sternum or manubrium sterni, (*b*) Meso-sternum or body of the sternum. (*c*) Xiphisternum (Xiphoid) or ensiform process of the sternum

(*a*) The manubrium is a triangular piece of bone which is broad anteriorly where it articulates with the clavicle, and which narrows rapidly to a subcylindrical apex at its junction with the first sternebra Its rough and convex ventral surface affords attachment on either side of a median ridge to the sterno-mastoid and pectoralis major muscles, whilst its concave and smooth dorsal surface gives attachment to the sterno-hyoid and sterno-thyroid muscles The thick anterior border of the manubrium is faintly marked by the jugular notch which is flanked by two irregularly quadrilateral facets for the sternal ends of the clavicles The facets are directed outwards, ventrally and anteriorly The lateral borders which converge to the median line present anterior and posterior facets: the anterior pair is for the first costal cartilages and the posterior' hemi-facets with similar ones on the first sternebra form cup-shaped cavities for the reception of the cartilages of the second pair of ribs

(*b*) The Meso-sternum or the body of the sternum consists of seven or eight discrete sternebræ which articulate end to end and are held together by fibrous connective tissue The transverse section of a sternebra is triangular in shape and presents dorsal and ventro-lateral surfaces. The articulated sternum presents just ventral to the lateral border a series of cup-shaped cavities into which are received the sternal ends of the related cartilages. In the dried sternum the cavities communicate by a foramen and in the fresh state are filled by connective tissue

(*c*) The Xiphoid process is a long flake of cartilage equal in length to two sternebræ Its ventral surface affords attachment to the costo-xiphoid ligaments and to a small part of the rectus abdominis whilst its dorsal surface gives attachment to the dorsal costo xiphoid ligament, and to some fibres of the diaphragm and a part of the transversus thoracis muscle. Anteriorly it articulates with the last sternebra and enters into the formation of the cavity for the ninth costal cartilage, whilst the linea alba gets attached to the tip of the Xiphoid.

The Ribs.

The ribs are elastic arches of bone and form the main portion of the skeleton of the thorax The number of ribs are liable to variation since there are more frequently fourteen pairs than fifteen When compared with the human subject, there is not much to choose between the two, so far as the percentage of presacral vertebræ is concerned For the pre-sacral vertebræ in the human subject number twenty-six of which usually twelve and rarely thirteen bear ribs, this gives nearly a percentage of fifty In Loris lydekkerianus the pre-sacral vertebræ are thirty in number and fourteen (sometimes fifteen) bear ribs giving again fifty per cent The fact that nearly fifty per cent of the pre-sacral Vertebrae are rib-bearing in both man and Loris lydekkerianus is of some interest and worthy of note.

The first nine ribs are connected ventrally through the intervention of the costal cartilages to the sternum directly and are consequently known as 'true ribs'. Of the remaining all except the last rib which is attached only to the vertebral column, are joined by their cartilages to those of the immediate predecessors thus getting an indirect attachment to the sternum. The latter are known as 'false ribs'.

The obliquity of the ribs varies; the first rib is the least oblique, whilst the tenth shows the greatest obliquity The intervening ribs present intermediate stages. From the eleventh to the last there is a gradual reduction in obliquity It is to be stated that the obliquity is from behind outwards, outwards and ventrally forming the angle of the rib and then ventrally inwards and posteriorly to its termination.

The tenth rib is the longest, and the others on either side decrease in length gradually The first rib is the shortest and the last, the floating rib is the weakest.

COMMON CHARACTERS OF THE RIBS

Each rib has a dorsal and a ventral extremity between which is the shaft The dorsal or vertebral end is composed of a head, a neck and a tubercle The head has two hemi-facets juxtaposed with the 'crista capituli' and the parts are about equal in size and enter into the formation of the vertebro-costal articulation. The crista rests on the inter-vertebral fibro cartilage The *neck* is the flattened portion immediately continuous with the head and it is placed ventral to the transverse process of the posterior of the two vertebræ with which the rib articulates. The ventral surface of the neck of the rib is, in its natural state, covered by parietal pleura, and the dorsal surface of the neck which is rough for the attachment of ligaments is pierced by a few nutrient foramina. On the dorsum of the rib and at the junction of the neck and shaft is the tubercle which has an articular and a non-articular portion The former articulates with the transverse process of the posterior of the two vertebræ with which the rib articulates

The non-articular portion is for the attachment of ligaments and the capsule of the joint there formed.

The shaft of the rib is flat with an inner and outer surfaces and cranial and caudal borders. The smooth and inner concave surface is marked by a groove at its posterior border It is prominent in the vertebral part and gets lost at a variable distance from the angle This groove lodges the inter-costal vessels and nerve The outer surface is smooth and convex. Near the vertebral end. from the apex of the tubercle runs a faint low ridge obliquely across the rib forming the 'angle' of the rib and here the bone is bent in two directions and also twisted on its long axis. The borders serve for the attachment of the inter-costal muscles

The head of the first rib is at right angles to the body; this prominent angle becomes more and more obtuse and rounded as we pass backwards to other ribs until in the last rib there is scarcely any angle The first two ribs are sub-cylindrical in shape and the others flatten out and increase in breadth in an orderly manner.

The first rib is the shortest of all On its head it supports a single facet for the vertebra. The neck is cylindrical and the tubercle protuberant. The thirteenth and fourteenth ribs have no tubercles and no 'angles' While the penultimate rib has a costal cartilage, the floating rib has none.

The Costal Cartilages —These differ much as to their connections, shape, length and disposition. The first costal cartilage is thicker and longer than the succeeding one The costal cartilages increase in length progressively till the first false cartilage, after which they decrease to the last The cartilages of the first nine ribs join the sternum directly, the cartilage of the tenth joins that of the ninth, and those of the eleventh, twelfth and thirteenth ribs join the costal cartilages of the tenth, eleventh and twelfth ribs respectively. The costal end of the cartilage is convex and articulates with the punched out end of the corresponding rib. The costal

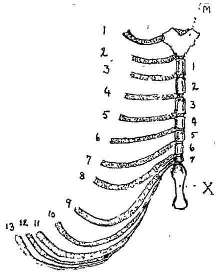

Fig. 7.

Diagrammatic sketch of sternum with costal cartilages M—Manubrium , 1—7 sternebræ ; x—xiphisternum ; 1—13 costal cartilages. (Note 10, 11, 12, 13 costal cartilages get indirect attachment.)

ends of the cartilage attached to true ribs are narrow, and become expanded before they articulate with the sternum; those attached to false ribs are broad at the costal ends and taper to rather very narrow structures as they proceed to get an indirect attachment with the sternum The first four costal cartilages are nearly horizontal while the others form an angle before ending in the sternum

We might now state that the thoracic vertebræ dorsally, the ribs and their cartilages ventro-laterally, and the sternum ventrally form the skeleton of the thorax. The thorax is a conical osseo-cartilaginous cage lodging and protecting the principal organs of circulation and respiration It resembles a dorso-ventrally compressed truncated hollow cone, and it presents a reniform outline in cross section. It is to be observed that the longitudinal diameter of the thorax ventrally is much shorter than that along the mid-dorsal line. The anterior opening of the cavity is irregularly oval in shape. It is bounded by the anterior border of the manubrium, the first rib with its cartilage and the centrum of the first thoracic vertebra

The posterior opening is not in one plane Whilst dorsally it is horizontal, it gradually develops a retreating angle the apex of which is on a much more cranial plane than the dorsal, the angle is formed by the cartilages of the four posterior penultimate ribs The oblique opening is flanked on the sides by the last rib and dorsally by the last thoracic vertebra At the apex of the costal angle is suspended the Xiphisternum The lateral diameter of the posterior as that of the anterior opening is greater than the dorso-ventral diameter. The base of the thoracic cavity is floored by the diaphragm.

From the foregoing description of the vertebral column and the thorax it is obvious that Loris lydekkerianus has more often fourteen thoracic vertebræ and fourteen ribs It is a well-known fact that the primitive vertebrates had a greater number of ribs and the thoracic region extended both anteriorly and posteriorly (Wiedersheim) and that 'phylogeny' has reduced the number of rib-bearing vertebræ, thus separating the original large cœlomic cavity from the thoracic cavity of the higher vertebrates. Thus the present-day mammals possess two cavities, the abdominal and the thoracic, which are completely separated by the diaphragm. That variation in the number of rib-bearing vertebræ in Loris lydekkerianus occurs has also been noted

The presence of fourteen thoracic vertebra more frequently than fifteen with the associated ribs in the same species of the animal is not without significance The smaller number of rib-bearing vertebræ suggests that a process of recession has taken place. The sternum of this animal is long and consists of seven or eight discrete sternebræ This reduction, whether in absolute length or in the number of sternebræ, is not of very great significance as the condition in this animal is similar to that in carnivores. But when the Xiphisternum is taken into consideration, it is found that it is nearly twice as long as a sternebra, and that its anterior half is ossified to a varying degree These features seem to indicate that the sternum is in a retrogressive phase. Further if it is remembered that the spurious ribs had in earlier forms an independent attachment to the Xiphisternum one can realise the enormity of the change that has taken place in the sternum of this animal. In addition to these, the ribs show definite thickening of the vertebral end which results in pushing the centre of gravity towards the back. This alteration in the centre of gravity of the animal is in favour of rendering it semi-erect. Further the sub-conical shape of the chest, a condition which is intermediate between the keeled primitive type of the carnivores and the barrel-shaped, dorso-ventrally compressed chest of man, offers important evidence The transverse diameter of the chest is, as has already been stated, greater than its vertical (dorso-ventral) diameter Considering that Loris lydekkerianus is as easily a pronograde as one which assumes a semi-erect posture, one need not wonder that the Viscera have not undergone vast adaptive changes. Thus for instance the heart shows a twist in its axis approaching the condition in Tarsius but it has neither descended towards the diaphragm nor is it very near the chest wall to produce a separation of the parietal pleuræ which retain the ligamentous character. The diaphragm has not shifted appreciably to lie nearer the heart either The lungs are multilobed To be brief, the factors that have determined the shifting of the centre of gravity and enabled the animal to assume the semi-erect posture, while at rest, in our opinion, are as follows —

(1) The reduction of the thoracic metameres and the associated ribs ,

(2) The reduction in the absolute length of the sternum, and in the number of sternebræ taking part in the formation of the sternum ,

(3) The reduction in the number of true ribs and spurious ribs ,

(4) The regression of the Xiphisternum and changes in the character of the ribs; and

(5) Finally, the shape of the thoracic cage.

The influence of the above-mentioned factors on the musculature of the regions concerned will be considered in our account of the myology of the animal

THE APPENDICULAR SKELETON.

The Pectoral Limb.

The bones of the pectoral limb may be studied under three heads ·—

(*a*) The bones of the shoulder girdle (1) The clavicle, and (2) the scapula

(*b*) The bones of the fore-leg (1) The humerus, and (2) the radius and ulna

(*c*) The bones of the fore-foot (1) Carpus, (2) the metacarpals, and (3) the digits

A. The entire pectoral limb measured from the summit of the head of the humerus to the distal end of the longest digit is 152 mm long The proportion borne by the entire limb to body length (the sum of the cervical, thoracic, lumbar and sacral elements) approaches that in man [The proportion referred to above is 187 : 100 in Tarsius ; 107 : 100 in man ; 101 : 100 in Loris lydekkerianus, under 80 in Perodicticus, and 75.3 ; 100 in Arctocebus.] The pectoral limb without the manus is less than the spine (body length), in this respect also Loris lydekkerianus resembles man and other lower primates.

The Bones of the Shoulder Girdle.

(1) The clavicle articulates medially with the manubrium sterni and laterally with the acromion of the scapula. It is a long bone placed horizontally on the ventral and anterior part of the thorax. It is somewhat like the italic letter "*f*" presenting a prominent concave lateral curvature (Text Fig. 8) Its lateral third is flattened vertically while the rest (the medial two-thirds) is prismoid in shape. In absolute length the clavicle exceeds that of Tarsius Compared to the spine it can be placed alongside that of Macacus, midway between man and the higher apes on the one hand, and Cebus and other Lemuroidea on the other. As compared to the scapula it occupies with Perodicticus a position between that of man and Hylobates on the one hand and Macacus, Cebus and other Lemuroidea on the other The breadth of the clavicle resembles in proportion that of man and Cebus.

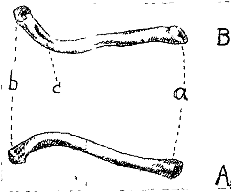

Fig. 8.

Diagram of clavicle (magnified). A—Natural position (Ventral view); a—sternal end, b—acromial end, B—Dorsal view, a—sternal articular facet; b—acromial articular facet, c—subclavian fossa.

The following table gives the details of comparison in so far as it relates to the clavicle :—

Clavicle	Length along curves	Length (straight between 2 ends)	Breadth (middle)	Length taking length of spine as 100	Length taking scapula as 100	Breadth taking length as 100
Loris lydekkerianus	96	0.85	0.08	16	80	8.3
*Man	6.8	6.0	0.5	21	92.3	8.3
*Hylobates	3.6	3.58		29.1	111.8	
*Macacus	2.4	2.2	0.2	15.6	58.8	10.0
*Cebus	1.8	1.5	0.12	14.5	62.5	8.0
*" Lemur "	1.5	1.45	0.15	9.7	58	10.3
*Perodicticus	1.4	1.3	0.13	12.7	81.2	10.0
*Tarsius	0.65	0.45	05	14.5	52.9	10

* From Mivart's paper.

The lateral third of the clavicle has two borders separating two surfaces. On the dorsal surface is the sub-clavian groove lodging the muscle of that name. There is no process or ridge marking the " coracoid tuberosity " except the margin of the sub-clavian groove. The medial two-thirds of the clavicle presents three borders and three surfaces The anterior and posterior borders are continuous with the acromial part. The third or the sub-clavian border is a continuation of the corocoid tuberosity and ends at the costal tuberosity These borders give attachment to the Deltoideus, Pectoralis major and Trapezius muscles The anterior surface of the acromial end is convex as in all primates except Hylobates. The posterior surface enters into the acromio-clavicular joint through a concave circular facet the rim of which is raised and rough for the attachment of the capsule and ligaments The sternal end of the clavicle presents a rounded triangular area directed medially and slightly posteriorly, and it bears on its posterior aspect a facet for articulation with the articular disc of the sterno-clavicular joint The facet is continued on to the dorsal surface for articulation with the cartilage of the first rib.

(2) The scapula or the shoulder blade is a flat triangular bone which presents three borders, three angles, three processes and two surfaces for study (Text Fig. 9). On its ventral angle is the shallow pear-shaped concavity for the head of the

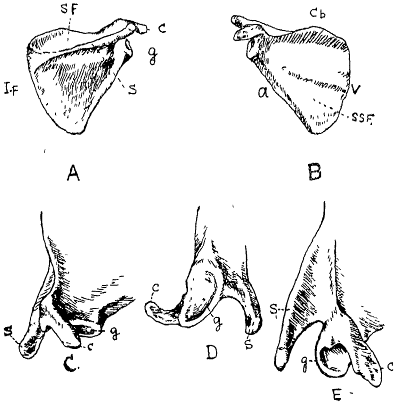

Fig. 9.

Diagram of Scapu C. D and E.—Three views of g glenoid; c.—coracoid and s.—spine, A—Dorsal view; c—coracoid, g—glenoid cavity; s—spine of the scapula, S F.—Supra-spinous fossa, I.F—Infra-spinous fossa; B—Ventral view, a—axillary border, cb.—coracoid or anterior border; V—Ventral border; S SF—Sub-scapularis fossa.

humerus. The length is measured by noting the distance between the anterior border of the glenoid cavity and the posterior angle and it is 30 mm which is about a fifth (20 per cent) of the body length. The other lemurs have the same proportion or thereabouts except in Perodicticus in which it is about 15.6 per cent. In man it is 22.8 per cent and in the Anthropoid apes it is much greater.

The anterior and ventral borders measure 21 mm. and 20 mm respectively.

The other measurements are shown in the following table:—

Scapula	From end of Glenoid surface to Posterior vertebral angle	Length axillary margin	Vertebral margin along curves.	Anterior margin	Length Glenoid surface	Breadth of Glenoid.
Loris lydekkerianus	1 2	1 0	8	.84	35	14
*Man	6 5	5 3	7 4	3 4	1 5	1 1
*Hylobates	3 2	3.1	2.6	1 75		
*Macacus	3 4	3 0	2.5	2 7	8	6
*Cebus	2.4	2 2	2.1	1 5	5	3
*Lemur	2 5	2 3	1 2	1 9	.55	3
*Perodicticus	1 6	1 2	1 8	1 1	.45	23
*Tarsius	85	8	.	75	3	2

Proportions of the Scapula	Axillary Vertebral margin as 100	Axillary anterior margin as 100	Post Vertebral angle	Angle of Glenoid with spine	Angle of Spine with Vertebral margin	Angle of Spine with axillary margin.
Loris lydekkerianus .	80	84	54	78°	97°	29°
*Man	125	64 1	40	80°	95°	55°
*Hylobates	86 8		30 35	96°	125°	15°
*Macacus	66 6	90	60	95°	90°	30° 37°
*Cebus	72 7	68 1	45	85° 95°	103°	30°
*Lemur	52 1	82 6	48	110°	120°	20°
*Perodicticus	125	91.6	55	98°	95°	42°
*Tarsius	43 7	87 5	65	97°	95°	24°

* From Mivart

A glance at the tabular statement given above will reveal that the scapula of Loris lydekkerianus is lemurine in character. It resembles the human scapula in the position of the spine, in the character of the vertebral border and in the nature of the glenoid cavity and differs widely from that of Macacus and Cebus.

The costal surface of the scapula presents a shallow sub-scapular fossa for the M subscapularis Just near the axillary border and almost parallel to it, is an eminence marking the line of insertion of the serratus magnus. Corresponding to the line of attachment of the spine is a concavity, which like the eminence referred to above extends from the vertebral border to the glenoid angle The tendinous fibres of origin of the subscapularis produce a well-marked ridge which runs across the surface from the vertebral margin to end near the glenoid angle The posterior part of the fossa is slightly convex as in the other lemurs

The dorsal surface of the scapula is divided into the supraspinatus and the infra-spinatus fossæ by the spine. The former fossa is concave and gives origin to the M. supra-spinatus The anterior border of the scapula, external to the supra-scapular notch, is prolonged anteriorly so as to increase the dimensions of an otherwise exceptionally small supra-spinous fossa. Though many of the Anthropoids including man have a small supraspinatous fossa as in Loris lydekkerianus, it is to be emphasized that there is no attempt on the part of the anterior border to enlarge the fossa as is the case especially in aged Cyanocephali As in other Primates the fossa is deepest at its vertebral end

The infra-spinatus fossa which is four to five times larger than the supra-spinatus is shallow with raised margins and it gives origin to the infra-spinatus muscle The axillary border which is prominent but not produced into a process as in Cebus, and which gives origin, along the border and its adjacent infra-spinatus fossa, to the Teres minor and Teres major muscles, resembles that of Hylobates It differs from the concave axillary border of Perodicticus and Nycticebus tardigradus Near the glenoid cavity and covered by the origin of the Teres minor muscle, is an expanded shallow groove for the circumflex scapular vessels

The anterior angle is truncated by the glenoid cavity and the posterior angle, which is about 54°, while giving origin to a part of Teres major is covered by Latissimus dorsi on its way to the Bicipital groove The dorsal or superior angle is rounded (the tangents about the angle making 84°) and is covered by M. trapezius.

The anterior margin which is extended is markedly convex and its medial concavity represents the "supra-scapular notch" which is not so well defined as in some Primates (man, Ateles, Chimpanzee), and which in Mycets is converted into a foramen.

The vertebral (supra-scapular) margin is, as in Perodicticus, convex but differs from that of Indris, Gorilla, Ateles and man. (In Indris it is straight while the others have a sinuous vertebral border) The vertebral border (supra-scapular border) is not so well ossified and is more or less cartilaginous.

The spine, a triangular plate of bone projecting from the dorsum of the blade of the scapula, crosses the medial four-fifths of the dorsal surface obliquely from the vertebral border towards the glenoid, and its superior end is nearer the anterior end of the vertebral margin But in Hylobates definitely and in Chimpanzees generally the spine commences nearer the posterior end of the vertebral margin. Along the free margin of the spine, commencing from the vertebral end, is noticeable a smooth flat triangular surface which occupies more than half the length of the spine This feature is presented also by the scapula of man, Orang, Mycetes and Arctocebus. The spine except at the acromion, is at right angles to the blade in the Primates usually but in Ateles, Nycticebus and *Loris lydekkerianus* it is antroverted whilst in Galago and Tarsius the spine is produced over the infra-spinous fossa

The spine remains rather distant from the glenoid as in the case of man, Ateles, Hylobates and Orang, further at the glenoid end the attached margin of the spine divides the area into the narrow supra-spinous and a broad infra-spinous area, extending the latter at this angle. This feature is also present in man, Perodicticus and Nycticebus but in Gorilla and Indris the two are of equal width, whilst the supra-spinous is the greater in Cebus and lower Simidæ

The acromion projects from the tip of the spine downwards at first and then curves, rather abruptly forwards to end as a flattened knob. It is long and comparatively narrow as in Ateles, Mycetes, etc, but is without a metacromion-like process as in man, Galago, etc The anterior bent part of the acromion bears on its dorsum a dorso-anteriorly directed articular facet for the clavicle The acromion does not project over the glenoid cavity and is more divergent.

The coracoid process is a curved projection attached by a broad flat base to the supra-glenoid region in continuation with the anterior border. It projects first cranially and medially with a slight ventral inclination up to the conoid tubercle and then twists on its long axis almost at a right angle so that it is now directed ventrally. The anterior and posterior surfaces of the proximal portion become the medial and lateral glenoid surfaces The tip of the coracoid is very divergent as in Perodicticus. It is very long and projects beyond the glenoid surface as in Ateles, other lemurs and man. In other primates it falls short of the level of the glenoid The conoid tubercle for the coraco-clavicular ligament is well marked as in *Hylobates*, *Indris* and Chimpanzee but it is ill-defined in other lemurs and man So far as we have been able to make out the Coraco-brachialis is the only muscle attached to this process as there is neither a Pectoralis minor, nor a short head for the Biceps although Mivart quotes Cuvier as having represented two heads for the latter muscle.

The glenoid cavity (Text Fig 9 C, D and E) forms the anterior surface of the head of the scapula, the neck is the slightly constricted portion behind the glenoid labrum The longest diameter is 6 mm and the broadest 4 mm. (proportion 100 67) and in this respect L. lydekkerianus resembles the other lemurs In other Primates the proportion is still greater (100 · 73 to 75) As in Nycticebus there is in this animal a twisting of the glenoid, producing an angle with the general plane of the blade of the scapula This can be easily noticed when the bone is held with the glenoid facing the observer. The anterior end of the glenoid presents a further medial twist.

The glenoid is well proportioned and is pear-shaped. The cavity is fairly deep for articulation with the head of the Humerus. The supra-glenoid tubercle is well marked and gives rise to the long head of the Biceps. The infra-glenoid tuberosity and a short area on the axillary margin gives attachment to the long head of the Triceps

The Bones of the Fore-leg.

The Humerus (Text Fig 10) —Though as in the human subject it is the largest bone of the Pectoral limb it is by no means the longest in the body It consists of a shaft and two ends, proximally the bone articulates with the scapula and with the Radius and Ulna distally

In all the Primates the humerus possesses similar fossæ and prominences, as those existing in man. Greater part of

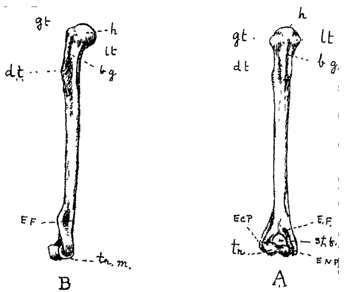

Fig. 10.

Diagram of Humerus A—Anterior view, h—head, l t—lesser tubercle g t—greater tubercle, b g—bicipital groove, d t—deltoid tuberosity, E C.P—Ectepicondyle, E.N P—Entepicondyle, E F—Entepicondylar foramen; tr—trochlea of humerus; S t.f—Supra-trochlear foramen B tr m.—medial trochlear margin, other lettering as in A.

the shaft including the lower end is straight but the head and a small adjoining part is convex forwards and slightly curved medially The articulating surface of the head is directed backwards with just a suggestion of an inward bend The width of the head conforms to the Primate type in being less than that of the tuberosities (head .25 inch; Tuberosities .3 inch). The shaft resembles that of Indris more than that of the other lemurs in which it is curved, and in having its upper part convex forwards it resembles Hylobates. The articular surface is of the intermediate type, i e., is directed backwards and inwards; and in other lemurs it is directed exclusively backwards and differs from the condition in man in whom it is directed exclusively inwards. The bend referred to however is slight and differs very much indeed from that of man, Orang, etc

The measurements relating to the humerus of Loris lydekkerianus and those of some other animals are given in the following table ·—

Humerus	Length of humerus	Breadth of humerus in the middle	Breadth of both tuberosities	Breadth between Condyles	Humerus Spine as 100	Humerus Scapula as 100	Breadth of Shaft length as 100	Tuberosities Total length as 100	Between Condyles Humerus as 100
L lydekkerianus	2 5	15	3	4	41 7	208	6	11 2	16
*Man	13 4	85	.18	2 55	47	206 1	6 3	13 4	19
*Hylobates	9 1	35	7	1	73 0	284.3	3 8	7 6	10 9
*Macacus	5 75	4	9	1 2	44 9	169 1	6 9	15 6	20 8
*Cebus	4 35	29	.57	82	42 2	181 2	6 6	13 1	18 8
*Lemur	4 05	3	62	.93	27 3	162	7 4	15 3	22 0
*Perodicticus	2 9	25	5	73	28 4	181 2	8 6	17 2	25 1
*Tarsius	1 2	1	21	31	38 7	141 1	8 3	17 5	25.8

* From Mivart

From the above tabular statement, it is observed that the proportion between the length of the humerus and the spine of Loris lydekkerianus approaches that of Cebus, and is less than that of man, Hylobates and Macacus but greater than that of Tarsius, Perodicticus and 'Lemur" The proportion between the humerus and the scapula is as noted above slightly greater than that of man whilst vast difference is observed when other forms are taken into consideration. The breadth of the shaft bears nearly the same proportion to its length as in man but is appreciably less than in "Lemur", Perodicticus and Tarsius.

The proximal end of the humerus comprises the head, the neck, the greater and the lesser tuberosities The head is nearly hemispherical in shape, the slightly constricted portion next to the articular surface is the neck which gives attachment to the articular capsule of the shoulder joint The neck is pierced by a few nutrient foramina of which two or three are prominent. The tuberosities are about on a level with the summit of the head, and in Hylobates they are decidedly below, whilst in Cheiromys they are slightly above the summit of the head. The insertion of the infra-spinatus is the most prominent; the Teres minor is attached at the lowest level on the radial tuberosity which has not developed a process as in some Primates. The Ulnar (lesser) tuberosity is so placed as to hide the neck and head of the bone when its front surface is viewed at This is also the case in the lower Simidæ, Cebedæ and other lemurs In Cheiromys, however, the 'lesser' tuberosity is equal in size to the 'greater'. The Bicipital groove or the inter-tubercular sulcus lodges the long head of the Biceps, and it is bounded by the radial and ulnar crests prolonged from the distal margins of the two tuberosities.

The lateral margin is the more prominent of the two and may be said to overlap the sulcus to a considerable extent. The medial margin is less prominent and rounded and gives attachment to the Teres major muscle. In this respect Loris lydekkerianus resembles Perodicticus

The Shaft is prismoid at the extremities and more or less cylindrical in between. It presents three borders separating three surfaces for examination. The anterior border begins as the radial crest of the Bicipital groove and ends at the coronoid foramen below, and in its upper part it is very prominent and gives attachment proximo-distally to the Pectoralis major and Deltoideus muscles The insertion of the latter is raised into a prominent ridge and marks the medial boundary of the extensive Deltoid tuberosity Distal to the Deltoid ridge the border is rounded The medial border which is the continuation of the medial crest of the Bicipital groove, ends at the medial epicondyle The tuberculation for the Teres major muscle is prominent and is about a third of that for the Pectoralis major in length, distal to the latter is the insertion of the coraco-brachialis (both the parts) up to a point, about an inch above the supra-condylar foramen The supra-epicondylar ridge affords attachment to the medial intermuscular septum.

The lateral border begins at the back of the greater tubercle as the extension of the insertion of the Teres minor muscle and ends at the lateral epicondyle. Distal to the insertion of the Teres minor, it gives origin to the lateral head of the Triceps up to the musculo-spiral groove (Sulcus Nervi Radialis) which is faintly marked and in which lie the Radial nerve and the Profunda Brachii Artery Beyond the groove the lateral border is very prominent and sharp, and it curves forward to end as the lateral supra-condylar ridge. It must be mentioned here that the lateral ridge is not produced laterally as in Notharctus, Hapale, Galago, Perodicticus and Lemur mongoz The outward expansion is much more prominent in Cheiromys and it is least so in man This portion is also called the supinator ridge as the Brachio-radialis muscle (O T. Supinator longus) takes its origin on its proximal moiety, distally the ridge offers attachment to the extensor carpi Radialis longus. There is no lateral intermuscular septum in this animal

The antero-medial surface, the least extensive of the three, forms the floor of the Bicipital groove into which the tendon of the Latissimus dorsi is inserted. The upper half (*i e*, above the musculo-spiral groove) of the antero-lateral surface is raised into a V-shaped plateaux with the apex disposed distalwards. This is the Deltoid tuberosity affording insertion to the Deltoideus. The lateral margin of the plateaux affords origin to a part of the lateral head of the Triceps. The Deltoid eminence extends to a shorter distance proportionately than in man as there is no necessity for this animal to develop any great mechanical efficiency involving the action of the Deltoideus.

The posterior surface is divided by the faint musculo-spiral groove into two areas each of which gives origin to a head of the Triceps.

The lower end of the humerus is flattened antero-posteriorly with a slight forward curvature. It consists of an articular surface and two epicondyles, and the articular surface is curved forwards The capitellum or the radial articular facet is convex and extensive only on the anterior aspect, whilst posteriorly it dwindles into a narrow area scarcely distinguishable from the trochlea. The line of demarcation between the capitellum and the trochlea can be made out only on very careful examination.

The trochlea articulates with the semi-lunar notch of the Ulna. Immediately proximal to the capitellar portion is the Radial fossa for the rounded rim of the Radius when the fore-arm is completely flexed. The corresponding fossa for the Ulna is not present, as this area is deficient and forms a foramen which in the fresh state is covered by a membrane. This forms on the one hand the coronoid fossa and on the other the olecranon fossa. The foramen whose diameter is about two millimetres is nearly circular The groove on the floor of the fossa winds spirally from before downwards, backwards and laterally. The medial margin of the trochlea is sharp and occupies about three-fourths of the arc of a circle, above the entepicondyle is the entepicondylar foramen which serves as a passage for the Brachial artery This feature is common to all Lemurs except Arctocebus and Perodicticus It occurs sometimes in Hapale. The conversion of the coronoid fossa into a foramen is also seen in Troglytes and sometimes in Hylobates, man and Macacus The olecranon fossa is deep as in man but it is shallow in other lemurs. The innermost margin of the trochlea projects beyond the radial margin as in Cebus, Galago, Nycticebus, etc., and in the Lemur and Hylobates it is above the radial margin The external condyle which looks outwards and forwards is distinct but not prominent as in man (or absent as in Hylobates and Cebus) The internal condyle projects inwards and more or less backwards and it is so bent downwards that it reaches beyond the centre of the medial circular face of the trochlea, but which in Cebus reaches almost the lower margin of the face. The surface of the humerus between the internal condyle and the innermost border of the *trochlea is lemurine in character*

From the foregoing account it is evident that the humerus of Loris lydekkerianus possesses certain features in common with that of the higher Primates. The characteristic features of the humerus of L lydekkerianus are as follows .—

1 The Delto-pectoral crest is V-shaped and ends in a pointed tip, and not as a gentle curve
2 There is no fossa to mark the site of insertion of the Latissimus dorsi muscle.
3. The tuberosities resemble those of man and Cebus
4. The shaft is straight with a very little convexity at its upper end
5. The head is elongate and oval.
6. The shaft is generally cylindrical
7. The supinator crest is medium but conspicuous. It is not produced outwards as in other lemurs
8 An entepicondylar foramen is present and its bony roof is inclined at an angle to the shaft
9. The entocondylar process is moderate in size suggesting weak Pronator Radii Teres and Flexor muscles
10. There is an external lip to the trochlea.
11. The olecranon fossa is deep

The Radius and Ulna are always distinct and separate bones among the Primates, and though approximated at the extremities they are divergent in the middle. The radius is the smaller of the two bones though in the natural position its distal end projects beyond that of the ulna. The divergence of the bones referred to above is caused by the radius as the ulna runs more or less straight. The radius is longer than the humerus

In the following table are shown the dimensions of the radius in some of the Primates —

Radius	Length of Radius	Transverse diameter of distal end	Length of Ulna	Length of Radius Spine as 100	Length of Radius Humerus as 100
Loris lydekkerianus	2 7	18	2 85	45	106
*Man	9 9	1 4	10 85	34 7	73 8
*Hylobates	10 13	61	10 3	82 3	111 3
*Macacus	5 5	62	6 25	42 9	95 6
*Cebus	3 68	41	4 2	35 7	84 5
*" Lemur "	3 71	4	4 6	25	91 6
*Perodicticus	3 10	36	3 5	30 3	106 8
*Tarsius	1 55	14	1.72	50	129 1

* From Mivart

From the figures given in the above table it is obvious that Loris lydekkerianus resembles Perodicticus when the radius and humerus are taken into consideration but that it comes nearest to Macacus is also evident when the radius and the spine are taken into account

The radius (Text Fig 11) which derives the name from its resemblance to the spoke of a wheel, is curved though not to such a degree as in Gorilla or Indris. It presents lateral and antero-posterior curvatures with the convexity backwards The proximal end of the bone comprises a head, neck and a tuberosity The head is a circular cup-shaped disc, permitting pronation and supination of the arms The cup articulates with the capitellum of the humerus. On the medial side of the head, is a facet for the radial notch of the Ulna. The remaining portion of the side of the head is smooth and cylindrical, and the annular ligament surrounding it allows rotation of the head during pronation and supination The constriction immediately next to the head is the neck. The radial tuberosity is well developed indicating the presence of a strong biceps.

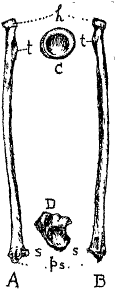

Fig. 11.

Diagram of Radius. A—Ventral view; B—Dorsal view; C—Head capitular surface; h —head, t —tubercle; S —Sustentaculum of Radius; ps.—styloid process

The shaft of the radius which is curved laterally and is cylindrical in cross section is thin and slender in its proximal part and it gradually assumes a prismoid shape and becomes thicker towards the distal part The lower end is thick and strong, a feature which is in keeping with the strong thumb which the animal possesses The margins and the sites of origin of muscles are not particularly prominent. The Ulnar border is rounded except for about a fifth of its extent nearer the proximal end where it is ridge-like The presence of this ridge implies the presence of an inter-osseous membrane which however is very weak The outer margin is rounded as in most primates but in man and sometimes in Cebus, Galago and "Lemur" it is a raised margin. 'The degree of distinctness of the ridges and depressions for muscular attachments are subject to individual variations" not only among the different families of Primates but within the range of the same species. Excepting an occasional impression for the supinator (S brevis) and a fairly frequent roughing for the Pronator Radii Teres, the other muscles fail to produce in Loris lydekkerianus, any impressions on the bone at their origin. The insertion of the Pronator Teres is marked by a roughness of the surface as in man, Hapale, etc, but a fossa for it is sometimes found in Macacus, 'Lemur', Perodicticus, Arctocebus and Tarsius.

The distal end which is placed on a more anterior plane is triangular in cross section. The carpal articular surface is concave and irregular in outline, and it is divided into two areas, by a faint ridge running ventro-dorsally, for the scaphoid and the lunate respectively. The surface for the latter is bigger and lies on a more proximal plane.

The distal (lower) end presents volar, dorsal and lateral surfaces, and the distal margin gives attachment to the capsule of the wrist joint The volar surface is rough at its edge and is marked by a shallow groove for the flexor Pollicis longus whilst the dorsal surface is marked by a deep groove common apparently to both the Extensor digitorum communis, and Extensor indicis proprius.

The lateral surface is rough and irregular, it is traversed by many grooves for the Extensor pollicis longus, Extensor carpi radialis brevis, and Extensor carpi radialis longus respectively. According to Mivart the groove for Extensor secondii internodii (Extensor pollicis longus) is distinct only in man, Chimpanzee and the Orang In some specimens of Loris lydekkerianus we find a distinct groove for this tendon

The styloid process situated at the antero-lateral angle of the distal end, is broad at its base but tapers rapidly to a sharp point and gives attachment to the Radial collateral ligament. At its base is the tubercle for the insertion of the supinator longus as in Hylobates, Cebus, 'Lemur' and Galago

On the dorsal aspect its base is grooved to lodge the tendons of Abductor pollicis longus and Extensor pollicis brevis. This is very marked as in other Primates indicating a strong and useful Pollex The lips and floor of the groove help to extend the insertion of the Supinator longus (Extensor carpi radialis longus).

"The sustentacular process of the Radius" which is situated on the medial aspect of the lower end of the Radius, is received into the hook-like articular facet of the lower end of the Ulna

Generally, the bowing of the Radius and Ulna is an adaptive modification which tends to increase the bulk and strength of the flexors of the arm of Arboreal primates but Loris lydekkerianus (a very sluggish arboreal animal which does not leap from branch to branch but which uses the hands in grasping and in ordinary locomotion) possesses only the radial flexors of greater dimensions.

The Ulna (Text Fig 12)—It must be stated that the length of this bone varies as does that of the Radius (see table, page 146) but it is always the longer of the two bones

The Ulna is a straight bone interposed between the humerus above and the carpus below, and it consists of a proximal massive end, a shaft which tapers distally into a thin and inconspicuous distal end, the head. The proximal end comprises the olecranon, the coronoid process and the sigmoid cavities.

The olecranon the pointed extremity of which forms the tip of the elbow when the arm is flexed is long as in other lemurs and lies in a line with the shaft. Its dorsal aspect is divided into two areas by a transverse ridge, and the subcutaneous part ventral to the ridge is covered by a bursa whilst the part dorsal to it gives attachment to the tendon of insertion of the Triceps brachii The margin of the process gives attachment to the capsule of the elbow joint Although the olecranon is lemurine in general character, its corona is flattened as in Cebus, Ateles and 'Notharctus' (see Fig, Gregory) The olecranon is directed outwards as in lower primates.

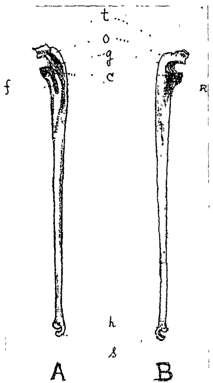

Fig. 12.

Diagram of Ulna A—Medial view, B—Lateral view; O—olecranon; t.—triceps impression, g—greater sigmoid cavity, C—coronoid process, R—Radial notch, f—origin of flexor digitorum profundus, h—head; s.—styloid process of ulna.

The disto-volar aspect of the olecranon forms with the proximal surface of the coronoid process the great sigmoid cavity (the semi-lunar notch of human anatomy), for articulation with the trochlea of the humerus, and a longitudinal curved ridge runs from the tip of the olecranon articular surface to the tip of the coronoid process dividing the semi-lunar notch into two moieties, the ridge itself articulating with the corresponding groove on the Trochlea. The coronoid process is attached to the proximo-ventral margin at the proximal end of the bone The proximal surface of the olecranon is directed proximo-medially, and it is bounded by a sharp margin which separates it from the distal surface all round, except on the lateral aspect where the lesser sigmoid notch is present The margin gives attachment to the capsule of the elbow joint The distal surface is semi-cylindrical and continuous distally with the general surface of the ulna. The impression for the Brachialis is a small triangular tubercle which is not prominent as in man

The lesser sigmoid cavity has as in higher Primates a clear rim separating it from the greater sigmoid cavity The margin of the lesser sigmoid notch gives attachment to the annular ligament which holds the head of the radius in position during pronation and supination.

The shaft which is nearly straight, thick and flattened from side to side in its proximal portion, becomes cylindrical in the mid-region whilst distally it tapers.

It is divided into three surfaces by three faintly marked borders. The lateral border is a faint ridge throughout and gives attachment to the Inter-osseous membrane The medial border begins at the supinator impression and ends at the volar margin of the styloid process The dorsal border commences at the confluence of the subcutaneous triangular area (see page 149) and ends on the dorsum of the styloid process. The volar surface which is smooth and convex from side to side presents an incomplete volar border just beneath the coronoid process. Beneath the radial notch is a rough area for the Flexor Digitorum Profundus, which in other lemurs is poorly marked, and immediately distal to which is a shallow depression for the reception of the radial tuberosity during pronation. On the inner aspect of the coronoid process is a long narrow depression for the supinator brevis, and this impression is wanting in the other lemurs in which the muscle is not attached to the ulna The presence of the prominent impression in Loris lydekkerianus is of importance as it indicates the progressive nature of the animal At the distal part of the bone is the site of origin of the Pronator quadratus which is marked by a roughening of the surface, and which in other lemurs (Lemur, Nycticebus) is a thickened tubercle

The medial surface of the Ulnar shaft which is subcutaneous does not call for any special remarks, and the dorsal surface of the shaft is incomplete in its distal part and it presents proximally a subcutaneous triangular area, on the lateral aspect of which is the flattened surface of origin of the three muscles (Extensores pollicis longior et brevior and Abductor pollicis longus) of the thumb

The distal end of the shaft presents a head and the styloid process The head is similar to that of the Radius The styloid process, however, is unlike that of any other Primate. It is fairly long and projects distally from the dorso-lateral angle of the head as a hook-like process. The summit of the head with the concavity of the hook forms a complex articular surface for the reception of the 'sustentaculum' of the lower end of the Radius The tip of the hook-like process gives attachment to the ulnar collateral ligament of the wrist joint The ulna does not take part in the formation of the wrist joint, and in this respect this animal differs from the higher Anthropoids and many of the lower Primates

The Bones of the Fore-foot (Manus).

The Manus (Text Fig 13) —The Manus can be said to consist of three sets of bones, *viz.*, the carpal bones, the

Manus.	Length of Manus	Length of Manus Spine as 100	Length of Manus Rest of *Pectoral* limb as 100	Length of Manus Radius as 100	Length of Carpus	Length of Carpus Spine as 100	Carpus as 100 Its breadth
Loris lydekkerianus	1 2	20	24 9	44 4	24	4	100
*Man	7 5	26 3	32 6	75 7	1 4	4 5	161 5
*Hylobates	5 9	47 9	30 8	58.2			
*Macacus	3 6	28 1	32 1	65 4	.6	4 6	166·6
*Cebus	3	29 1	36 1	81.5	43	4 1	125 5
*'Lemur'	3 2	21 6	39 5	86 2	57	3 8	128 8
*Perodicticus	2 4	23 6	41 7	77 4	44	4.3	96 6
*Tarsius	1 8	58 1	45 0	116 1			

* From Mivart

metacarpal bones and the phalanges The Manus of Loris lydekkerianus differs generally from that of the other Primates as can be seen from the above table.

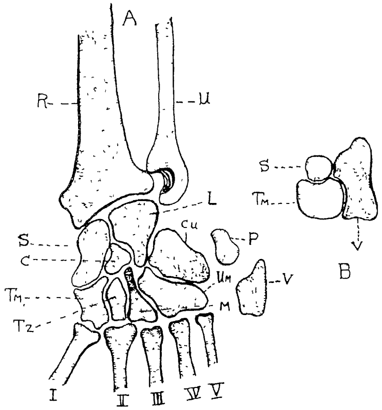

Fig. 13.

Diagrammatic representation of Manus A—Bones of the Manus, R—Radius; U—Ulna; S—Scaphoid, L—lunate, Cu —Cuneiform, P—Pisiform, C—Centrale, TM —Trapezium, TZ —Trapezoid, M—Magnum, UM.—Unciform, V—Ventrale carpi, I, II, III, IV and V—Metacarpals, B—Diagram to show the relationship of Os Ventrale carpi to the scaphoid and trapezium.

The carpus consists in all of *ten* small, irregularly angular or rounded bones which together constitute the wrist, and it articulates proximally with the Radius and with the metacarpals distally The bones are arranged in a proximal row of three (the scaphoid, the lunate and the cuneiform) and a distal row of four (the trapezium, the trapezoid, the magnum and the unciform) Between these rows of bones is situated the Os centrale There is a fairly well-developed pisiform and also an additional bone which we name ' ventrale ' on the palmar surface of the carpus.

The *scaphoid* is an irregular short bone, as indeed all the carpal bones are, placed on the radial extreme of the wrist. It presents articular surfaces for the lunate, the centrale and the trapezium , with the last named bone the scaphoid forms a peculiar joint The scaphoid and the trapezium have each a process which projects towards the volar aspect, and the articulating surface of the process of the scaphoid is received into a concavity on that of the trapezium

The *lunate* is almost a globular bone, its distal portion being moulded to produce a semi-lunar facet, the projecting lips of which are directed ventro-dorsally. The base of the bone contributes the greatest area for articulation with the Radius Distally it articulates with the unciform, disto-medially with the cuneiform and laterally with the centrale. The ventral lip of the lunar surface overlies the unciform and the magnum

The *cuneiform* is a more or less quadrilateral bone which articulates with the lunate proximo-laterally and embraces the base of the unciform disto-medially

The *pisiform* is an oval bone, which as in man articulates with the cuneiform only. The tendon of insertion of flexor carpi ulnaris is attached to this bone

The *centrale* which is very small-sized is not visible on the back of the articulated carpus ; and it is received into a concavity on the ulnar surface of the *scaphoid* Further it articulates with *lunate* and *trapezium* also In this respect it differs from Tarsius where the bone has contact with Trapezoid and Unciform.

The *trapezium* placed on the disto-radial aspect of the wrist, presents on its distal process, an articular surface divided into two by a fine ridge, one for the second metacarpal and the other for the trapezoid. The same process has on its lateral aspect a round articular facet exclusively for the first metacarpal bone On the ventral process is the grooved articular facet for the scaphoid. It does not possess any articular facet for the centrale though the margins of the two bones are juxtaposed The dorsal surface of the bone is large and contributes to the dorsum of the wrist.

The *trapezoid* articulates with the centrale, the magnum and the second metacarpal The magnum has a head, a neck and a broad body, and it articulates with the centrale, the lunate and the unciform proximo-medially, and both with the second and whole of the third metacarpal, distally whilst it does so with the magnum laterally. The unciform has a broad base and a ventral hook-like projection, the hamulus of the unciform, which articulates with the 'ventrale'. The unciform conjointly with the magnum articulates with the lunate proximally, cuneiform medially, with the magnum laterally, and distally with both the fourth and fifth metacarpals

The ventrale—This bone is found as in Perodicticus (*d*) in the transverse carpal ligament It is difficult to decide as to whether this should be considered as a separate entity of the carpal elements, or just a calcification of the transverse carpal ligament A factor lending support to the latter view, if indirectly, is the fact that the transverse scapular ligament of the human being which gets calcified in old age forms an arch over the great scapular notch Calcification of ligaments is not uncommon or unusual in the animal series It is likely that in this animal as in others when it occurs, the transverse ligament has developed a calcified bony structure That this explanation is probably the correct one becomes fairly patent when we remember the axiomatic 'fundamental inertia of nature towards the creation of new types' Inasmuch as this bone could not by any means be construed to be a modification of the original carpal elements, it must be considered to be an extra element It may be asserted that this bone is either a sesamoid or a calcification of the ligament. The bone cannot be said to be a sesamoid as it is not so far as we could make out in dissections, in connection with any tendon of insertion of any muscle. The development of this structure will be described in a future communication For the present we consider the bone to be the result of calcification of the transverse ligament probably brought about by variations in pressure which the ligament is subjected to. We might state here that the weight of the animal, when it is behaving as a pronograde, is transmitted to the ground through this area which is provided with a pad of soft tissue

The *"ventrale carpii"* is sub-triangular in shape, with the apex turned towards the arm; its volar surface is flat and smooth, whilst its dorsal surface is divided into the dorso-medial and dorso-lateral surfaces by a ridge which is near the ulnar border of the bone. The tunnel formed by this bone is meant for the passage of the tendons of the flexors of the digits and the carpus (Text Fig 14). It is of interest to note

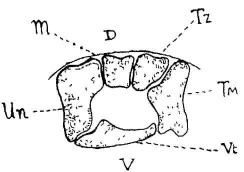

Fig. 14.

Diagrammatic representation of Osseous tunnel for the flexors of the fore-arm. V—Ventral aspect, D—Dorsal aspect; Un —Unciform; Vt.—Os Ventrale, TM.—Trapezium, TZ.—Trapezoid, M—Magnum.

that this extra bone was first described by Van Campen as early as 1859 in his memoir on "The Potto of Bosman". (Reference from Mivart's paper)

The Metacarpal Bones.—The first metacarpal bone which measures on an average 7 5 mm. in length is placed on the radial side of the hand. It is divergent, relatively thicker than the other metacarpals and articulates with the trapezium. Its proximal articular surface is broad and flat, whilst the distal articular surface is rounded (overhanging the ventral surface)—an arrangement that facilitates the play of the digits and indicates the degree of activity of the animal

The second metacarpal is the shortest and is about 6 mm. long It resembles the first metacarpal but its proximal end articulates with the trapezium, trapezoid, magnum and to a small extent with the third metacarpal.

The third metacarpal, the longest of the series, is about 9 mm long and it articulates with the magnum and the adjacent metacarpals.

The fourth and fifth metacarpals measure 8 mm. and 7.5 mm. respectively and articulate with the distal end of the unciform.

The *phalanges* conform to the general characteristics of those of the other Primates with slight modifications. Thus the first digit has two phalanges, the others possess three phalanges each. The proximal phalanges are club-shaped bones with two broadened extremities. The ungual phalanx is conical in shape The details of measurements of bones of the digits are shown in the following table ·—

Digits.	Individuals	Total length of the digit.	Total length including metacarpals.
	mm	mm.	mm
1st Digit . .	5 5+3	8.5	16
2nd Digit .	7+3+1	11	17
3rd Digit .	8+5+2	15	24
4th Digit . .	10+6+2 25	18 25	26.25
5th Digit	8+5+1 75	14.75	22.25

The *Manus* is used partly like a *hand* for purposes of eating. We have observed this animal, holding its food in its hands, while in the squatting posture, and carrying it to the mouth.

Sometimes it uses only one of its hands for this purpose. So far as we have been able to observe the animal in the cages in captivity and also in a state of nature during the day, it has not got to do much of running. It uses its fore-limbs mostly for purposes of clutching and clinging to branches of trees; and in this performance the index finger is not much used. So we find that the index finger is not only very slender but also the smallest of the digits This condition should be considered more as a functional adaptation than as an index of the systematic position of the animal.

The *Carpus* is like that of Cebus, narrow proximally and broad distally. The Pollex is not very divergent and the approximation of this finger to others is so much improved over the condition in Notharctus that we may consider the manus to function like a real hand and not as a mechanism in " Brachiation " only. The fingers are tapering as is indicated by the form of the distal phalanx, and in this respect the animal resembles Notharctus Further every finger has a distinct nail and the fourth finger, unlike that of man and other higher anthropoids, is the longest The mobility of the metacarpophalangeal joints assists the animal in holding the food with its finger tips; and the perfectly co-ordinated action of the associated muscles of the limb renders the supple and intricate movements of the hand in the act of carrying food to the mouth possible

The Pelvic Limb The Pelvis.

The Pelvis may be studied under two heads :—

(*a*) The Pelvis proper, *i e*, Pelvic girdle

(*b*) The bones of the hind-limb : The Femur, the Tibia, and Fibula, Tarsus, Metatarsus and Phalanges.

(*a*) The Pelvis (Text Fig 15) is formed by the two innominate bones flanking the sides and forming the ventral walls, the sacrum and the appended coccyx filling up the dorsum. There is no 'false pelvis' and the 'true pelvis' is a cavity whose walls are deficient in many places. It has anterior and posterior outlets; and on either side the obturator foramen covered by a membrane renders the sidewalls

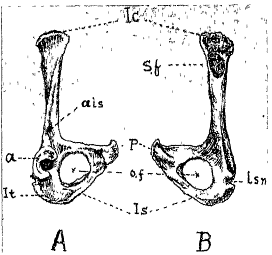

Fig. 15.

Diagram of Os Innominatum. A—outer view, B—inner view, I—Ilium; P—Pubis; Is.—Ischium, Ic.—Iliac crest, ais.—tubercle homologous with the anterior inferior iliac spine; O f.—obturator foramen, It —Ischial tuberosity; Lsn.—lesser sciatic notch, a—acetabulum; sf.—sacral articular facet

defective. The brim or the inlet of the pelvis is peculiar in that its margins are in one plane as only in man. The body of the pelvis is on the same level as the cotylo-sacral tract of the Ilium. The diameters of the inlet and outlet of the true pelvis, according to Owen's nomenclature, as compared to those of man are given in the following table —

Brim	Man.	Loris lydekkerianus
Inlet —		
Transverse	4 6	0 45
Oblique	4 6	93
Antero-posterior	4 0	95
Outlet —		
Transverse	3 3	5
Antero posterior	3 4	65

The sacro-vertebral angle is the greatest in man due to his erect posture. In Loris lydekkerianus the angle is the complement of 167° whereas in man it is a complement of 130° (♂) and 117° (♀) The pelvi-vertebral angle, i e, the angle between the vertebral column and a line joining the apex of the symphysis to the promontory of the sacrum is 115° in Loris lydekkerianus and 150° in man thus showing that in the former the symphysis is on a higher level than in the latter. The anterior inclination of the pelvis to the vertical is 25° in Loris lydekkerianus and only 10° in man Considering the femoral attachment as the fulcrum and the tip of the symphysis as the ventral projection and the central line of the vertebræ as the dorsal projection, we get the power arm equal to .5 inch and the weight arm as .2 inch forming a lever of the first order the mechanical efficiency of which is as 5 : 2 whilst in man it is as 3 . 2.

Further, it is of interest to observe, that the sacro-iliac articular area is oval and elongated more or less in the cranio-caudal direction

The form of the pelvis resembles that of Tarsius, it is noteworthy that in Loris lydekkerianus the two pubic bones do not meet end to end but are just opposed to each other, a small length of fibro-cartilage intervening between the two bones. There is an undoubted reduction in the contribution of the ventral ends of the pubic bones to the symphysis

The *Os innominatum*, the largest of the flat bones of the skeleton, is a tri-radiate bone formed by the fusion of the *ilium*, the *ischium* and the *pubis*. On the outer surface of the innominate bone is an almost circular, cup-shaped cavity, the acetabulum, dorso-ventral to which is the obturator foramen covered by a membrane in the natural state.

The details of measurements of the Os innominatum are given in the following table :—

Os innominatum.	Length of Bone	Crest following Curves	Crest as a straight line	Crest of Ilium to Spine of Ischium	Spine of Ischium to nearest point of its Tuberosity	From Ilio-pectineal eminence to Ischial Tuberosity	Length of Symphysis	Antero-posterior diameter of Acetabulum	Conjugate diameter of Pelvis	Oblique diameter of Pelvis	Transverse diameter of Pelvis	Ilio-pubic angle	Ilio-ischial angle I.	Ilio ischial angle II
Loris lydekkerianus .	1.65	5	4	1 25	1	7	14	35	8	98	48	97°	173°	158°
Man*	9 3	9 2	6.5	3 8	1 45	4 6	1 4	2 19	4 5	4 8	4 75	180°	113°	148°
Hylobates*	4 75	2 75	1 83	3 1	6	1 62	1 2	.78	3	2 75	2 25	110°	140°	
Macacus* ..	5 4	1 7	1 33	3 13	84	2 02	1 35	68	2 12	2 01	1 8	108°	164°	178°
Cebus*	3 3	1	73	2 36	6	1.4	8	43	1.58	1 5	1 28	107°	187°	192°
"Lemur"*	3 7	8	62	2 64	47	1 54	63	61	1 5	1 6	1 45	120°	165°	165°
Perodicticus*	2 65	46	45	2.03	19	1 01	18	46	1 69	1 34	1 09	119°	166°	172°
Tarsius* .	1 17	24	.24	.93	14	.43	.19	.17	7	68	.48	98°	172°	166°
"Loris"* . .	1 46	31	3	1 1	08	5	13	.23	74	71	.33	88°	170°	180°

* From Mivart

The ilium is the elongated rod-shaped anterior (cranial) portion of the innominate bone and it articulates with the sacrum anteriorly by its expanded flat surface and extends backwards as far as the acetabulum. The outer surface of the ilium is slightly concave with the expanded thickened border known as the 'crest'. Further there is the anterior iliac spine at the end of the ventral margin, and the superior anterior and superior posterior iliac spines dorsally. The ilio-pectineal line which commences at the pectin pubis ends at the anterior (inferior) iliac spine and forms the crestlike ventral margin of the bone. The part corresponding to the "ventral margin" of other Primates is a ridge bifurcating at the anterior end of the ilio-pectineal line and running an oblique course dorsally to end dorsal to the most anterior part of the margin of the acetabulum; and not far from the anterior acetabular margin is a low prominence which corresponds to the anterior inferior iliac spine of man. The ilio-pectineal eminence is, in most of the specimens, a sharp-edged, ridge-like prominence, on the brim of the pelvis

The inner surface of the ilium at its expanded anterior part presents a rough "auricular" surface, anterior to which is a depression for the Zygapophysis of the first sacral vertebra and just behind the crest is an irregular tuberculated area for the attachment of ligaments.

The nature of the sacro-iliac joint and the ventral symphysis is of some interest It is a well-known fact that in the thoroughly pronograde animals, the sacro-iliac joint area is disposed in such a manner that its long axis is in a dorso-ventral plane. But in Loris lydekkerianus the sacral segment of the vertebral column is wedged in between the two iliac bones in such a way that the ilio-sacral contact area is nearly oval having its longest diameter at an angle of 30° to the long axis of the sacrum. The joint area, though only slightly elongated, is in a more or less cranio-caudal plane The ventral symphysis exhibits some noteworthy features. In lower animals such as the pig both the bones (Pubis and Ischium) take part in the formation of the symphysis but in Loris lydekkerianus as in man a very small part of only the pubis is involved in the symphysial articulation. The change in the plane of the ilio-sacral joint area, the complete exclusion of the ischium from the ventral symphysis and the reduction in the pubic contribution to the symphysial contact area can be attributed to the change in the posture of the animal already referred to

The ischium is the hinder part of the Os innominatum and it takes part in the formation of the acetabulum. The acetabular part is the body of the bone, and the part which is in line with the ilium is the superior (dorsal) ramus from the end of which the posterior ramus shoots ventrally The ischial margin of the acetabulum is sharply raised above the bony surface producing a shallow sulcus in which runs the tendon of the obturator externus muscle, before reaching the Trochanteric fossa. The prominent spine of the ischium arising from its superior border forms the limiting lip of the lesser sciatic notch, and it gives attachment to the sacro-spinous ligament. The superior ramus of the bone bears the rugose, elongated ischial tuberosity which reaches the acetabulum and the ischial spine. The free forward margin of the tuberosity forms the boundary of the lesser sciatic notch, and the tubercle gives origin to the hamstrings. The ischial tuberosity is strongly everted, a condition probably due to the semi-erect posture of the animal. The posterior ramus of the ischium meets the posterior ramus of the pubis The obturator foramen is more or less circular and is enclosed by the two posterior rami referred to above.

The pubis might be said to consist of three portions, the body, the vertical ramus and the posterior ramus. The portion entering into the formation of the symphysis is the body and the fork-like projections therefrom the two rami. The body which is elongated ventro-dorsally, presents an outer concavity ; the vertical ramus is very slender and forms about a fifth of the acetabulum There is no pubic spine , the ilio-pectineal line is fairly prominent. The posterior ramus which is slender, and much narrower, completes the obturator foramen, by fusion with the ischial ramus

The *acetabulum* is an almost circular cavity into which the head of the femur fits ; and it is formed by the three elements of the innominate bone. The cavity is directed downwards and laterally and its prominent rim gives attachment to the capsule of the hip joint opposite the obturator foramen (the ventro-lateral margin) ; the margin is incomplete and in the natural state is bridged across by the cotyloid ligament.

The details of measurements of the acetabulum are given in the following table :—

	Depth	Largest diameter	Transverse diameter.	Cotyloid notch at rim.
Acetabulum	4 1 mm	5 8 mm	5 mm	3.5 mm.

The depth is measured at the part corresponding to the upper wall of the acetabulum of man

The margin of the acetabulum is dented in two places marking the site of fusion of bones The cavity presents an auricular facet for the head of the femur and a depressed area which is continuous with the notch, lodging in the centre the ligamentum teres. The latter is attached on one side to the head of the femur and on the other along the whole length of the cotyloid (transverse acetabular) ligament.

The outer margin of the ischium is, as in man, convex 'from the prolongation upwards of the tuberosity'. The outer surface of the ilium is Lemuroid in character inasmuch as in its lateral view the whole of the acetabulum is exposed.

A study of the following table reveals that the pelvis of Loris lydekkerianus resembles that of man in many respects, *e g.*, the proportionate length of the bone, the proportion of the acetabulum, the breadth and length of the innominate, the conjugate diameter of the pelvis and the relation of the length of the innominate bone to that of the femur There is however great disparity between the two, so far as the length of the iliac crest and that of the symphysis pubis are concerned.

Among the Primates the absolute length of the symphysis is the smallest in Loris lydekkerianus.

PROPORTIONS OF THE OS INNOMINATUM

Os Innominatum	Spine 100 Extreme length of innominate	Spine 100 Crest (Ilium) measured as straight line	Spine 100 Length from Ilio-pectineal eminence to Ischial tuberosity	Length of Innominate 100 Antero-posterior diameter of Acetabulum	Spine as 100 Length of Symphysis pubis.	Breadth of Pubis 100 Length of Innominate	Conjugate diameter 100 its breadth	Length of Femur 100 Length of Innominate
Loris lydekkerianus	27.2	6.7	11.8	21	2.3	202	100	58.8
*Man	32.6	22.8	16.1	23.5	4.8	195.7	105.5	50.2
*Hylobates .	38.6	14.8	13.1	16.4	9.7	211.1	75	56.9
*Macacus	42.1	10.3	15.7	12.5	10.5	300	84.9	81
*Cebus	32.1	7	13.5	12.9	7.7	258.5	81	64.2
*" Lemur "	25	4.1	10.4	17.9	5.8	287.9	83.5	48
*Perodicticus .	25.9	4.4	9.9	17.3	1.7	243.1	64	77.9
*Tarsius . .	37.7	7.7	13.8	14.5	6.1	243.7	68.5	46

* From Mivart

The Bones of the Pelvic Limb.

The Femur (Text Fig 16)—The femur which is the strongest bone of the pelvic limb is a little shorter than the ulna but longer than the tibia. It is like the humerus more or less cylindrical in its proximal two-thirds and flattened in its distal third. It consists of a shaft and the proximal and distal ends.

The proximal end includes a head, neck and two trochanters

The head is connected with the shaft by a comparatively thin, flattened and constricted neck, which makes an angle with the shaft The head is nearly globular and has on its proximo-medial aspect a depression for the attachment of the ligamentum teres To its medial margin is attached the articular capsule The greater trochanter which projects, above the end of the shaft just falling short of the level of the head of the bone, is a flattened irregular prominence embracing the lateral aspect of the bone ; and it is convex laterally but

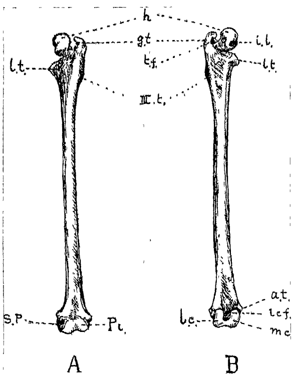

Fig. 16.

Diagram of Femur. A—Ventral view, B—Dorsal view, h—head, g t —greater trochanter, l.t —lesser trochanter, III t.—third trochanter, t.f.—trochanteric fossa, i l.—impression ligamentum teres, S P —Sulcus for Popliteus tendon, P.i.—Patellar impression, l c —lateral condyle, m.c.—medial condyle, I c f —Inter condyloid fossa, a t —adductor tubercle.

the surface projecting beyond the upper end is deeply concave and is known as the trochanteric fossa into which the obturator externus muscle is inserted The anterior border is prominent throughout and the posterior border is raised and prominent only in its upper half The lesser trochanter which is a plate-like projection from the inner aspect of the bone is flattened from before backwards and affords attachment to the ilio-psoas tendon, its lower border becomes continuous with the medial border of the shaft. There is an inter-trochanteric line in front connecting the two trochanters, but there is no inter-trochanteric crest as such There is no evidence of a linea aspera and its three radiations.

The Shaft.—As stated above the shaft is cylindrical in its proximal two-thirds while its distal third is flattened. It might be said to possess three surfaces separated by three borders The anterior border runs diagonally from the tip of the anterior aspect of the greater trochanter to the medial epicondylar ridge This is rounded and separates the ventro-lateral from the ventro-medial surface. The medial and lateral borders limit the posterior surface of the bone; and the lower portion of the posterior surface forms the proximal half of the popliteal fossa. The medial border ends below as the adductor tubercle

The distal end comprises the two condyles and epicondyles The condyles are two curved processes provided with articular surfaces for the tibia. They are separated posteriorly by the inter-condyloid notch and anteriorly prolonged on the distal end of the bone as two ridges which fade on the distal end of the shaft. These two ridges enclose an area which is convex proximo-distally and concave from side to side and which articulates with the *patella* and lodges the quadriceps tendon The patellar surface is not continuous with that of the tibial articular surfaces. The medial condyle is of the same dimensions and shape as the lateral. The inter-condyloid fossa is bounded by the medial and lateral surfaces of the lateral and medial condyles respectively. The floor of the fossa is separated from the shaft by a narrow ridge, the linea inter-condyloidea. It is pierced by many nutrient vessels The medial condyle at its anterior part gives attachment to the posterior cruciate ligament. The linea inter-condyloidea marks the line of attachment of the capsule of the knee joint.

The Epicondyles.—The cutaneous surface of each condyle presents a medial and lateral epicondyle. The medial epicondyle, the more prominent of the two, affords attachment to the tibial collateral ligament while the lateral epicondyle gives origin to the lateral head of the gastrocnemius Below

DIMENSIONS OF THE FEMUR.

Femur.	Length of Femur	Transverse diameter, middle of Shaft	Antero-posterior diameter, middle of Shaft	Extreme width at condyles	Angles formed by neck with Shaft.	Angle formed by shaft with horizontal.	Length of Femur with Spine as 100	Length of Femur with humerus as 100.	Breadth at Condyles with length of Femur as 100	Breadth of Shaft with length as 100
Loris lydekkerianus .	2 8	.15	.13	.35	130°	92°	47 4	106.5	12 5	5 4
Man* .. .	18 5	1 05	1 13	3 15	135°	103°	64 9	138	17	5 6
Hylobates* . .	8 35	38	.37	1 02	135° 145°	92°	67 8	91 7	12 2	4 5
Macacus* . . .	6.66	.4	46	1 16	145°	92°	52	115 8	15 9	6 9
Cebus* . ..	5.15	.29	3	.76	135°	95°	50	118.3	14 7	5 6
"Lemur"* .	5 8	.34	.36	.79	132°	92° 103°	39 1	143 2	13 6	5 8
Perodicticus* .	3 4	27	27	.53	145°	95°	33 3	117.2	15 5	.
Tarsius* .. .	2 54	.10	.13	22	135°	94°	81 9	211.6	8 6	3 9

*From Mivart.

and dorsal to the prominence are the pit and the groove for the origin of the popliteus, and for its tendon respectively. This is very marked owing to the adoption of the peculiar sitting posture (when the knee is flexed) by the animal. The fibular collateral ligament also gets attached in this neighbourhood.

It will be seen from the above table (Dimensions of the Femur) that except Tarsius, Loris lydekkerianus has the shortest femur as to absolute length, in relative length to spine also it exceeds that of Perodicticus, and "Lemur". As compared to the humerus also it occupies a very low position indeed, the only exception being hylobates. As regards the breadth it conforms to the general feature of Primates in being slender The lateral expansion of the bone is gradual downwards in Loris lydekkerianus, hylobates and "Lemur" but it is sudden in man and chimpanzee, the intermediate condition being found in Arctocebus, Perodicticus and Tarsius. The shaft is more or less circular in cross section as in most primates but in man it is angular, and in Tarsius it is laterally compressed The linea aspera is absent but in man, hylobates, Ateles and mycetes it is very prominent. The neck is quite lemurine in character being very short, but it is well defined in man and least so in Gorilla. The *greater trochanter* is .4 inch long and 2 inch broad and is pointed at its upper end. In man and Perodicticus it is truncated It is very large and disproportionate to the length of the femur, and it is nearly on a level with the summit of the head, but in Gorilla it rises above that level In man, Orang and sometimes in hylobates it is considerably below the summit of the head.

The external margin of the *greater trochanter* is continued as the prominent gluteal ridge to end in a rudimentary but definite third trochanter as in Lemur, Galago and Tarsius The trochanteric fossa is lemurine in being very small but deep ; in man, Gorilla and Perodicticus it is shallow The lesser trochanter which is of considerable size is plate-like as in other lemurs. It is placed very near the head of the femur whilst in other forms it is placed at a relatively greater distance from the head. The inter-trochanteric line is faintly indicated as in the other lemurs but it is well marked in man and simiidæ. The posterior surface between the trochanters is flat and broad for the insertion of the quadratus femoris as in all Lemurs and Hapale. The head of the femur is slightly transversely compressed and it is inclined anteriorly and medially. The pit for the ligamentum teres is prominent and deep but it is absent in Gorilla and sometimes in Orang. The condyles are about equally prolonged backwards but in others except man, the internal condyle projects further backwards than the external. The inter-condyloid surface, behind, is wide as in Simiidæ and Perodicticus.

The Patella.—This is the largest of the sesamoid bones and is incorporated in the Quadriceps femoris tendon at the level of the knee-joint. It is quadrilateral in shape with two surfaces. The proximal border gives attachment to the Quadriceps tendon and the distal border to the ligamentum patellæ. Its anterior surface is rough and covered by connective tissue and tendinous prolongations of the various muscles of the Quadriceps. The posterior surface of this thin flake of bone enters into the formation of the knee-joint and lies on the patellar surface of the femur on extension and on the inter-condyloid fossa during flexion. It is covered by synovial membrane and some amount of articular cartilage in its natural condition. The femoral surface is convex from side and slightly concave proximo-distally. In some specimens we could notice a vertical ridge on the femoral surface dividing it into medial and lateral halves.

The *tibia* (Text Fig. 17) consists, as other long bones of the body, of a shaft, proximal and distal ends. The proximal or the upper end comprises the medial and lateral condyles, the inter-condylar eminence and the tuberosity

The lateral condyle is large and convex in both directions but its posterior margin curls distally. The median condyle is relatively smaller and concave ; and it has a raised rim.

The inter-condylar eminence is an oblique ridge of an indefinite position ; antero-laterally and postero-medially, it has depressions meant for the attachments of the anterior and posterior cruciate ligaments and the medial and lateral menisci. The tuberosity is rough and gives attachment to the patellar tendon. The proximal (upper) end as a whole is longer transversely than antero-posteriorly and the posterior half overhangs the shaft; and on the under-surface of the lateral condyle is a facet for the upper end of the fibula.

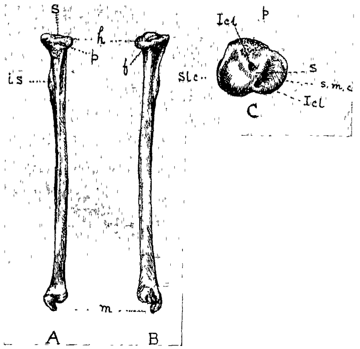

Fig. 17.

Diagram of Tibia A—Ventral view, B—Dorsal view; C—Proximal surface of tibia (enlarged) S—spine of tibia, h—head, p—patellar impression, f—fibular articular area, is —impression for combined insertion of semimembranosus, semitendinosus and gracilis, m—medial malleolus, s.l.c.—convex surface for lateral condyle of femur; s.m c —Concave surface for the medial condyle; I.c l —impression of cruciate ligament.

The Shaft—The most striking feature of the shaft is the sharp crest (shin) in front and this part of the bone is more or less triangular in cross section, when *in situ* the bone produces a median concavity from above downwards and a lateral convexity. The anterior border (crest) runs from the tuberosity to the median angle of the lower end; the lateral border is scarcely a ridge marked in the middle three-fifths of the shaft. The posterior border extends from the line of cleavage of the two condyles to the postero-median angle of the bone The antero-medial surface, which is extensive and sub-cutaneous, presents at its upper part a rough impression for the Sartorius Semitendinosus and Gracilis muscles of the thigh. The lower (distal) end of the tibia consists of the medial malleolus and the distal articular facet. The medial malleolus is a prolongation of the medial margin, the lateral surface of which articulates with the medial surface of the astragalus; its concave medial surface is divided by a fine vertical ridge into two compartments for the passage of the tendons of the Tibialis posterior and Flexor digitorum longus muscles The anterior border presents a groove in which the Tibialis anterior is lodged. The lateral border has a facet for the reception of the lower end of the fibula. The distal end has an irregular articular facet continuous with the articular surface of the medial malleolus for articulation with the proximal surface of the astragalus Embracing the foot of the malleolus is a groove into which fits the elevation on the astragalus Lateral to this, the articular surface presents a convex elevation.

The *fibula* (Text Fig 18) is the slenderest and the longest bone in the body and it is placed on the outer side of the tibia with which it is bound by strong ligaments The thickened nodular upper end (head) articulates with the tibia through an articular facet on its proximo-medial aspect, and lateral to this is a rough area for the attachment of the fibular collateral ligament The shaft is slender, flattened from before backwards with two crests which separate the anterior and posterior surfaces. The shaft is concave medially The distal end is not as thick as the head, and it has two articular facets, one on the proximo-medial aspect for articulation with the tibia, and the other on the distal surface The latter articular facet has a ridge-like elevation the lateral extreme of which reaches a more distal level than the medial end, and this along with the articular surface of the tibia forms the common articular area for the Astragalus the lateral surface of which is embraced by the fibular part. At the junction of the tibia and fibula is formed a retreating angle into which the lateral ridge of the astragalus is received Dividing the external surface of the malleolus into two is a ligament on either side of which run the tendons of the Peroneus longus and Peroneus brevis muscles respectively.

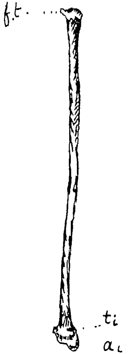

Fig. 18.

Diagram of Fibula f.t.—facet for tibia, t.i.—tibial impression; a i.—astragalar impression.

DIMENSIONS OF THE TIBIA.

Tibia.	Length of Tibia.	Greatest breadth between Tuberosities	Antero-posterior diameter of Shaft	Length of Tibia with Spine as 100	Tibia with Femur as 100	Tibia with Humerus as 100	Tibia with Radius as 100.	Antero-posterior diameter of shaft with Tibia as 100	Width of Tuberosities with Tibia as 100.
Loris lydekkerianus	2.6	35	12	44	92 9	100	99 85	4 6	13 5
Man* .	14.9	2 87	1 61	52 2	80 5	111 1	150 5	10 8	19 2
Hylobates*	7 1	1 02	5	57 7	85	78	70	7	14 3
Macacus* .	6 25	1 11	53	48 8	93 8	108 6	113 6	8 4	17 7
Cebus* .	4 81	74	44	46 7	93 3	110 5	130 7	9 1	15 3
"Lemur"*	5.08	78	5	34	87 5	125 4	136 9	9 8	15 3
Perodicticus*	3 32	.6	27	32	97 6	114 4	107	8 1	18
"Loris"* . .	2 48	32	15	43 5	97 2	110.2	100	6	12 9
Tarsius*	2 54	25	18	81 9	100	211 6	163 8	7	9 8

* From Mivart.

An analysis of the above table brings out certain interesting features of the tibia of Loris lydekkerianus. In absolute length tibia is seen to be the shortest The extreme breadth between the condyles is greater only than that in Tarsius and "Loris". The shaft of the bone is also the slenderest. It is shorter than femur, equal to the radius and longer than the humerus In Tarsius, Cheiromys and Hapale the tibia is longer than the fermur, but in man it is shorter than femur. The other primates present either shorter radius and humerus (Hylobates) or longer, the latter condition being the general rule As compared with the spine, Tarsius in which tibia and femur are equal in length, reaches the greatest proportion, others lie between 40 and 60 to 100, the "Lemur" and Perodicticus being less than 40 "Loris" approaches Loris lydekkerianus.

"The Tibia is most cylindrical in Lorisinæ", *less so in Loris lydekkerianus* ‘ most laterally compressed in Tarsius and most massive in Simia" (Mivart). The tubercle of the tibia is as high up as in Tarsius, and in man it is slightly lower; but in others it is much below the upper margin of the tibia. The peroneal condyle projects more than the tibial and overhangs the Tibialis anterior muscle area in L lydekkerianus. In Tarsius the projection of the condyle is the least. The outer facet is convex but in Ateles, Indris and man it is flat or concave. The posterior part of the inner articular facet ‘inclines strongly downwards’ as in Galago and Perodicticus, in all others it is more or less concave.

The Peroneal surface which in other Lemurs is strongly concave is here convex from side to side and flat from above downwards for the Tibialis anterior muscle. The crest of the tibia is very prominent; and the shaft is convex outwardly and in man, Indris, Orang it is almost straight but it is sigmoid in Hapale, Indris (sometimes) Galago and Tarsius.

The malleolus appears to arise from the anterior rather than the medial border of the lower end, as in Perodicticus The articular surface of the malleolus is at right angles to the distal surface and not at an obtuse angle as in Gorilla or Orang

There is no prominent process separating the grooves for Flexor hallucis longus and the Tibialis posterior as in Nycticebinæ. The distal articular surface is 'horizontal transversely' as in man but in other Lemurs it slopes upwards The anterior and posterior margins descend equally but in some Cebidæ and Lemuroidea the anterior margin descends further than the posterior The distal articular process is subquadrate generally but in this animal (L. lydekkerianus) it is lemurine (triangular) with a prominent antero-posterior prominence.

The pit for the tendon of Semi-membranosus and Gracilis is very strongly marked and the surrounding surface of the bone is raised above the general level In Lemurs it is often slight but in Indris a tubercle projects downwards immediately beneath it

The Fibula.—The fibula by far the slenderest bone is always distinct from tibia and its length varies in accordance with that of the tibia It is convex outwards. The head of the bone articulates with the tibia by a linear groove, a feature which is shared by Nycticebinæ. As regards the surfaces, borders and fossæ we can but quote Mivart who states the fossæ which more or less excavate the surface of the fibula and the ridges which divide them are in no Primate developed to such a degree as they generally are in man. Yet Simia, etc., approach him rather nearly in this respect. Very generally there is an anterior ridge and often a 'posterior ridge' as in Loris lydekkerianus.

The Pes.

The Pes of Loris lydekkerianus consists of the usual elements · Tarsus, Metatarsus and Phalanges In the following table dimensions of the Pes are noted ,—

Pes	Length of Pes.	Length of Pes with spine as 100.	Length of Pes with rest of Pelvic limb as 100.	Length of Pes with Tibia as 100	Length of Pes with Manus 100.	Length of Tarsus	Length of Tarsus with Spine as 100	Length of Tarsus with Pes as 100	Length of Tarsus as 100 : breadth	Length of Tarsus with Carpus as 100.	Longest digit without meta-tarsal with Tarsus as 100
Loris lydekkerianus	2	33 3	36 36	76.9	166 6	.6	10	30	66 7	250	140
* Man . .	10 1	35.4	30 2	67 7	134.6	4 7	16 4	46 5	48 0	335.6	70
* Hylobates . .	5	40 3	32 3	70 4	84.7	1 4	11.3	28	50		150
* Macacus . .	6	46.8	46 4	96	166 6	1.91	14.9	31 8	50.7	318.3	113 6
* Cebus . .	4 4	42 7	44.1	91 4	146 6	1.42	13 7	32 2	40 1	330 2	119 7
* "Lemur" .. .	4 5	30 4	41 3	88 5	140.6	1 6	10 8	35 5	40	280 7	111 2
* Tarsius .	2 72	87.7	53 5	107	151 1	1 22	39.3	44 8	15 5		80 3
* "Loris" .	1 82	31.9	36.1	73.3	151.6	58	10.1	31 8	44.8	322.2	170 6

*From Mivart

The dimensions of the Pes of Loris lydekkerianus, as can be seen from the above table, resemble those of "Loris". The pes and the tarsus are the smallest. The proportion of the pes to the spine approaches that of man. As compared with the manus the pes resembles that of Macacus. Tarsius alone possesses a longer pes than the tibia Man and Hylobates have the smallest sized pes The Tarsus resembles that of Hylobates and "Lemur", as compared with spine. Loris lydekkerianus has the broadest tarsus among the Primates, the narrowest being that of Tarsius. As compared with the carpus, the tarsus of Loris lydekkerianus bears the smallest ratio, even other "Lorises" having longer tarsus.

The tarsus (Text Fig. 19) consists of the usual seven bones . *Astragalus*, *Calcaneus*, *Scaphoid*, *Cuboid*, *Ectocuneiform*, *Mesocuneiform*, *Entocuneiform*, and the "Os ventrale".

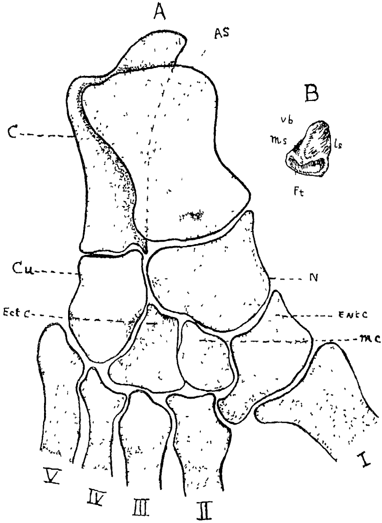

Fig. 19.

A. Diagrammatic sketch of Tarsus As —Astragalus, C —Calcaneus; Cu.—Cuboid; N —Navicular; Ect c.—Ecto-cuneiform; M c.—Meso-cuneiform, Ent c.—Ento-cuneiform; I, II, III, IV, V—Meta-tarsal bones.

B. Diagram of Ventrale Tarsii. Vb.—Ventral border; ms. and ls.—Medial and lateral surfaces, Ft,—Groove for the flexor tendons.

The *Astragalus* (Text Fig. 20) consists of three parts: *body*, *neck* and *head* The body is the irregularly formed portion of the bone, which articulates with the tibia and fibula

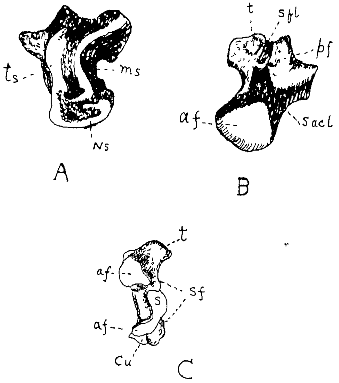

Fig. 20.

Diagrams of Astragalus and Calcaneus.

A—Dorsal view of Astragalus, ts —trochlear surface, ms —medicel malleolar surface; Ns —Navicular surface.

B—Ventral or Plantar surface of Astragalus; t —tubercle, G fl.—Groove for the flexor tendons, pf —posterior articular facet; a f —anterior articular facet, S.acl —sulcus for astragalo calcaneal ligament.

C.—Calcaneus (Dorsal view), t.—tuber, sf —sulcus for the flexors, Cu.—facet for cuboid, a.f —articular facet for Astragalus, S —sustentaculum tali

above and the calcaneus below. The neck is rather long and connects the clublike head with the body. The upper surface of the bone presents an articular and a non-articular portion, The articular surface which is trochlear in shape extends over the whole of the body; and it is divided into two distinct areas by a prominent curved ridge which is concave medially. The irregularly triangular saddle-shaped area, lateral to this ridge, is for articulation with a similar surface on the lower end of the fibula; and the ridge referred to above is received into the recess formed by the junction of the astragalar articular surfaces of the tibia and fibula. The trochlear area is bounded medially also by a prominent curved ridge which has the same inclination as the lateral ridge and which separates malleolar articular surface of the tibia from the distal astragalar articular surface. The trochlear surface is therefore bounded by two parallel ridges which are concave medially. Posteriorly the boundary is formed by a ridge which marks the line of attachment of the capsule of the joint, the anterior boundary though not prominent is clear and ends abruptly on the dorsum of the neck of the bone. The dorsal surface of the neck is rough for attachment of ligaments. The posterior surface of the bone presents a deep groove with two lips for the tendon of the Flexor hallucis longus muscle. The medial lunar concave articular surface is for the medial malleolus. At its posterior extremity is the posterior astragalo-tibial ligament, which with the corresponding posterior astragalo-fibular ligament forms a sling in which the astragalus is held and allowed to have its hinge-like movement on the tibia and fibula. The groove between the malleolus and the distal articular surface of the tibia lodges the medial ridge of this surface; and the whole of the convex distal articular facet rests on the trochlear surface. This surface is concave from side to side, with a central groove which runs a sinuous course almost parallel to the ridges. During the flexed condition of the ankle, the neck of the astragalus makes an angle with the line of the tibia, owing to the obliqueness of the trochlear surface; but during extension it comes to lie more and more in a line with the tibia, till on complete extension it is almost in a line with the shaft of the tibia This movement is greatly aided by the pressure of the fibula on its facet and also that of the scaphoid (navicular) on the head of the astragalus The most prominent feature of the plantar surface of the astragalus is the "inter-osseous groove" which embraces the V-shaped prolongation of the distal articular surface This groove does not extend far on the lateral aspect, whilst on the inner aspect it reaches the lateral angle of the head. In the natural condition the groove is filled by connective tissue and affords attachment to the inter-osseous calcaneo-astragaloid ligament; and it separates the common facet for sustentaculum tali and the navicular from the crescentic articular facet which articulates with the ectal facet of the calcaneus. The *head* of astragalus is flattened from side to side with convex upper and lower surfaces and a convex free margin Its long axis is directed downwards and medially and the long axis of the entire bone, it should be noted, crosses the long axis of the calcaneus at an acute angle so that the hind foot is slightly inverted in the natural state. This condition is helpful to the animal to hold on to branches of the trees during locomotion and at rest. That the foot during fœtal life is inverted and that it undergoes eversion during development and assumes its natural position in normal man is well-known. In Loris lydekkerianus the eversion is very slight and this indicates the retention in this primitive animal, of an embryonic condition as a permanent feature

The head of the astragalus consists of an extensive articular facet, part of which articulates with bones, and the remaining part of which is supported and held in position by strong ligaments The navicular articular facet occupies the whole of the upper surface and the rounded free margin; and it articulates, below, conjointly with the Naviculo-calcanear ligament, with the medial two-thirds of the triangular articular facet

With its apex directed posteriorly this facet which forms the border of the "inter-osseous sulcus" is convex in contour and by its lateral one-third articulates with the sustentaculum tali of the calcaneus It will be noticed that the astragalus does not articulate with the cuboid

The main features of the astragalus of Loris lydekkerianus are :—(1) The neck is longer than in the other lemurs but shorter than in Notharctus. (2) The trochlea is narrower and deeper (3) The ectal facet has a deep concavity and the impression for either the posterior astragalo-fibular or Tibial ligaments is not well marked

The *Calcaneus* (see Text fig 20 C) has a plantar surface, an astragalar articulating surface, the tuber and the cuboid articular surface. The shaft of the bone runs a straight course and its distal end presents an articular surface for the cuboid. The facet is an incomplete socket (for the cuboid), its inner margin is deficient and is marked by a rough depression for the attachment of the calcaneo-cuboid ligament The cuboid is placed in a line with the calcaneus. The plantar surface is faintly arched so that the most dependent parts of the tuber and its distal extremity rest on the ground This surface is very narrow and merges laterally with the ventro-lateral surface and is limited medially by a sharp curved ridge On the medial aspect of the bone is a groove formed at the expense of the tuber and the shaft in which lie the Tibialis posterior, Flexor digitorum longus, Flexor hallucis longus and posterior tibial vessels and nerve The astragalar articular surface which is a fairly extensive one has two facets The ectal facet situated proximo-laterally is separated from the other portion called the ' sustentaculum tali " by a depression (scarcely a groove) the " inter-osseous sulcus" which latter gives attachment to the interosseous ligament. The sustentaculum overhangs the groove on the medial aspect of the shaft and as its name indicates supports the head of the astragalus (talus) The tuber may be said to possess a head, a neck and a body The head is a rough convex hemiglobe for the attachment of the Tendo-achillis. The neck is scarcely recognizable except on the dorsum and the body is the expanded portion that joins the tuber to the shaft On its dorsum is the groove already referred to ; and the free margin begins at the head and extends to end at the distal end of the bone at a tuberosity which gives attachment to the short plantar ligament The plantar surface is rough and convex.

The calcaneus forms with the astragalus a specialized articulation allowing of only rocking movements. This evidence however is not sufficient to ascribe any leaping habits to this animal Being a pronograde animal its tuber is directed downwards with an inner inclination The sustentaculum is very near the distal end, so that coupled with the fact that the tuber which forms the power arm is equidistant from the weight arm (located in the astragalo-calcanear joint) it becomes obvious that the leaping tendencies of the animal are nearly inconspicuous

The *Cuboid* is more nearly wedge-shaped than rectangular, its ectal surface is flat. Proximally the cuboid has an articular surface for the calcaneus and medially it articulates with the navicular and entocuneiform whilst distally it does so with the whole of the fifth and part of the fourth metatarsal On the dorsal surface is a narrow deep groove for the tendon of the Peroneus longus muscle

The *Navicular* is an irregular shaped bone placed in the middle of the Tarsus; it is the place of convergence of the three cuneiformes with their attached digits It is placed in an inclined plane being directed inwards, downwards and slightly backwards Thus it is enabled to flank medially, by its undersurface, the deep gutter for the flexor tendons. The gutter is in effect the continuation of the one described in relation to the calcaneus. The inclination of the bone primarily helps in the thumb-like manifestation of the Hallux. The bone is held in position by the strong wide naviculo-calcaneal ligament which is attached on the one hand to the whole length of its proximal margin and on the other to the ' sustentaculum tali ' and the inferior lip of the tibia Further it supports and articulates with a considerable portion of the turned in head of the astragalus. Proximally it articulates with the head of the astragalus through a heart-shaped facet and distally with all the cuneiformes The facet for the ecto-cuneiform is concave whilst those for the meso- and ento-cuneiformes are convex On the medial aspect of the bone is a rough area to which part of the ento-cuneiform is apposed and is bound by fibrous tissue. At the postero-inferior corner of the bone is a rough area for the attachment of the Tibialis posterior muscle.

The *ecto-cuneiform* is a wedge-shaped bone whose base is on the dorsum of the foot, and the sharp margin of which is on the plantar aspect. It is placed antero-posteriorly (ventro-distally) in the foot, and its narrow proximal end bears a facet for articulation with the Navicular whilst the wide distal end is concave and articulates with the major portions of the third and fourth meta-tarsals. The inner side articulates by a narrow proximo-distal facet (nearer the dorsum) with the meso-cuneiform and with the navicular by another facet. The lateral surface bears two diagonally placed facets, separated by a sulcus (in which is the cubo-ento-cuneiform ligament in the fresh condition) which runs from the proximal ventral corner to the distal dorsal corner of the bone, for articulation with the cuboid

The *meso-cuneiform* is the smallest of the tarsal bones and its long axis makes an angle with that of the calcaneus and presents plain surfaces which meet at an edge on the plantar aspect. This bone, the dorsal surface of which is irregularly rectangular articulates with the ecto-cuneiform laterally, and proximally, with the navicular through a rather large concave facet, and medio-distally with the meso-cuneiform and the second meta-tarsal This bone is pressed upon on all sides by other bones which transmit their thrust from all directions

The *ento-cuneiform* completes the arch of the instep and reaches the lowest level on the medial aspect. It is very irregular in shape and like the navicular is inclined and flanks medially the gutter on the plantar surface On its dorsum, at the proximal end is a concave facet for the navicular, and a prominent tubercle at its summit for articulation with the hallux, while on its medial aspect is a triradiate concavo-convex facet for the hallux The distal margin has no facets, while its lateral face bears facets for the meso-cuneiform and the proximal end of the second meta-tarsal bone, the facet for the latter being double connected by a ridge.

In addition to the tarsal bones described above, there is in Loris lydekkerianus a peculiar ossicle which may be named *Ossis Ventrale Tarsii* The presence similarly of an extra bone in the corpus has already been noted. Such structures have been described in only one other Primate—Potto (Perodicticus)—by Von Campen This bone is pyramidal in form with a deep groove on its distal base for the lodgement of the tendons of Flexor digitorum longus (which is destined for the hallux) and Flexor hallucis longus The groove is converted into a trochlear tunnel as it is bridged over by a strong ligament The tibial aspect of the bone appears to give origin to the short muscles of the big toe The bone itself is held in position below the ento-cuneiform by ligaments, and appears to form the pivot on which the two arms of the shears (hallux on one aspect and the remaining toes on the other) act when the animal clutches at supports by the hind limbs.

The hallux is the strongest of the toes, and the most active and powerful agent in the progression of the animal; when it clutches at the branches, the hallux aided by its powerful adductors presses against the side of the branches and at the same time the pad between the hallux and the second toe is fixed. The remaining toes together with the pads of the foot function as the other blade of a pair of pincers. The muscles attached to the big toe are very strong and develop sesamoid bones ; the associated meta-tarsal and the phalanges are relatively massive. The first meta-tarsal has at its proximal end an asymmetrical irregularly heart-shaped concavo-convex facet for articulation with the ento-cuneiform , and the margin of this facet is raised for the attachment of ligaments which hold the bone in position. Its ventro-lateral angle has a very prominent tubercle, directed postero-medially to which the Peroneus longus tendon is attached The outer surface of the bone bears a tubercle which abuts against the base of the second meta-tarsal, a circumstance that renders it impossible to bring the hallux parallel to the other toes. Though adduction is thus impossible the hallux and the other toes are opposable The shaft of the bone narrows towards the distal end where it forms the head for the proximal phalanx; and the articular facet on the head is extended to a slight extent on the dorsum allowing of a limited extension of the digit. The phalanges are also stouter than those of the other digits. The distal phalanx has a clubbed extremity The first meta-tarsal measures 11 mm whilst the second, third, fourth and fifth meta-tarsals measure 11 mm., 11 mm , 10.5 mm., and 10 5 mm , respectively All of them possess a shaft with two distal extremities By their proximal ends they articulate with the distal ends of the tarsal bones, whilst at their distal ends each bears a digit The distal articular surfaces are rounded distally and flattened ventro-dorsally and they extend equally both on the ventral and dorsal aspect allowing of considerable amount of flexion and extension. The proximal attachments deserve special mention. The fourth and fifth meta-tarsals articulate with the cuboid, and the second, third and part of fourth with the ento-cuneiform and the first meta-tarsal with the ento-cuneiform only whilst the contiguous meta-tarsals articulate among themselves

The Phalanges.—Excepting the hallux which has only two, the others have three phalanges each. The proximal phalanges conform to the usual type in having a shaft and two extremities. The proximal extremity is flattened whilst the distal end is convex to allow of the play of the phalanges on one another or on the meta-tarsals as the case may be.

The distal phalanges have some interesting features In dealing with the manus mention has been made of the peculiarity of the distal phalanx and attention has been drawn to its pointed nature Similar features are found in the distal phalanges of the pes, except the ungual phalanx of the hallux which is lemurine (*i.e* , expanded), and that of the second digit which carries a claw, is rudimentary.

DIMENSIONS OF THE DIGITS.

Digits	Lengths of individual Phalanx mm	Total mm	Length of Digits including the meta-tarsals. mm
First bony digit .	7+4	11	22 5
Second bony digit	7 5+3+2	12 5	23 5
Third bony digit	11+6+2 75	19 75	33 75
Fourth bony digit .	12+7+3	22	32 5
Fifth bony digit .	10 5+6+2 5	19	29 5

Taking all facts into consideration it is clear that as in the manus, the fourth digit is the longest in the pes. The hallux with its two phalanges only is the shortest digit and the second digit though slightly larger than the hallux, is the smallest and is of very little practical utility to the animal.

THE PES AS A WHOLE.

It may be stated at once that the pes of Loris lydekkerianus is not typical of the arboreal leaping lemurs ; it is rather suggestive of a sub-cursorial type. Though the phalanges are long and slender, it resembles the Lepilemur in the possession of relatively slender meta-tarsals. The arching of the meta-tarsals makes an approach to the condition in higher Primates (macacus). The joint at the trochlea is hinge-like as in other primates The crossing of the Astragalus and Calcaneus is of some interest The angle made by the neck of the astragalus with the axis of calcaneus is not, since it is less inclined, typical of the Lemuroidea. This disposition of the neck and the prominent medial ridge of the trochlea tend to indicate its affinity with higher forms. On complete extension of the foot, the neck of the astragalus lies in a line with the tibia ; this would not have been possible if the inclination of the neck were not small. The foot is always held in an inverted position to facilitate firm grasp of the branches of trees during rest and locomotion. The head of the astragalus is held on a higher level than the cuboid owing to the transmission to it, the pressure of the divergent hallux, through the ento-cuneiform and the navicular. Further the ventro-dorsally compressed head of the astragalus reduces the flexional mobility of the foot and the play of the navicular on the head. The calcaneus is, except for the more distal position of the "sustentaculum tali", of the Lemuroid type generally. This factor coupled with the expanded and elongated tuber has the effect of rendering this animal more of the mildly sub-cursorial than of the leaping type. We have observed the animal both in its natural haunts and for long periods in the laboratory. We have not seen the animal leaping from branch to branch in its natural state, and none of those in the laboratory have shown a tendency to leap about even when placed in position from where it would be best to leap. It should be noted that the *ecto-*, *meso-* and *ento-cuneiform*, bones are more vertically placed than in other lemurs. The *ecto-cuneiform* is narrower proximally as in Notharctus and the *cuboid* which is more compressed than is usual presents a narrow deep groove for the Peroneus longus tendon. The *hallux* is divergent but opposable to a considerable extent. A consideration of the pes will not be complete if the second digit is not mentioned. It is slender, small and is provided with a claw which is sometimes used in scratching the irritating surface of the body and sometimes in dislodging insects from the crevices of bark of trees.

The Sesamoid Bones.

Most of the sesamoid bones are usually lost during the preparation of the skeleton. The description here offered of these bones is based on X-ray photographs of the partly cleaned Manus and Pes.

In the manus there appear to be in all six sesamoid bones The first digit has two sesamoid bones situated at the metacarpo-phalangeal joint and the inter-phalangeal joint respectively. The second digit has none The third, fourth and fifth digits have one each situated at the metacarpo-phalangeal joint On the outer aspect of the carpus in relation with the trapezium is a sesamoid which helps in extending the articular surface for the first metacarpal bone.

In the pelvic limb a sesamoid has been found in relation with the tendon of the Popliteus. This bone which is situated at the level of the upper border of the tibia on its dorsal and outer aspect strengthens the Popliteus by relating it to the head of the fibula. In the foot also there are six sesamoids. The hallux has two sesamoids whilst the remaining toes have one each. We cannot definitely state at this stage the nature of the associated tendons.

All the measurements, except where specially mentioned otherwise, are in inches.

SUMMARY.

A summary of important features of the Vertebral Column and the Appendicular Skeleton of Loris lydekkerianus :—

1 The absence of spinous processes in the cervical vertebræ (Exception: the second and the seventh)

2. The presence of an extra foramen in the Atlas for the muscular branch of the intra-osseous part of the vertebral artery

3. Large number of thoracic and lumbar vertebræ with an anticlinal vertebra

4. The formation of the sacrum by four vertebræ two of which take part in the formation of the sacro-iliac joint.

5. The cylindrical shape, the discrete nature and the variation in number of the coccygeal vertebræ.

6. The presence of two convex curvatures between the sacral and cervical curves

7. The immobility of the lumbar vertebral articulation.

8. The peculiar shape of the sternum.

9. The resemblance of the clavicle to that of Macacus and Cebus.

10 The spine and the vertebral border of the scapula resembling that of man The peculiar medial inclination of the apical portion of the glenoid cavity.

11 The relatively long humerus with an entepicondylar foramen

12. The sub-cylindrical shape of the Radius and Ulna.

13. Proportionately short Manus

14 The large size of the Os pubis and the very small ilio-pubic angle and the very small absolute length of the pubic symphysis.

15. The relative positions of the lesser trochanter and the head of the Femur and the presence of a small third trochanter.
16. The presence of a sesamoid in the Popliteus tendon.
17. The presence of "Os ventrale carpi" and "Os ventrale tarsi" in the Manus and Pes respectively.

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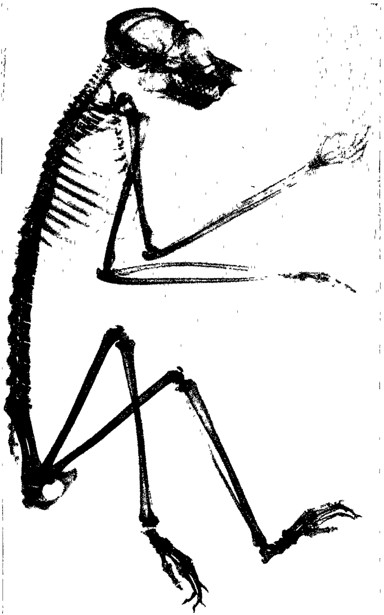
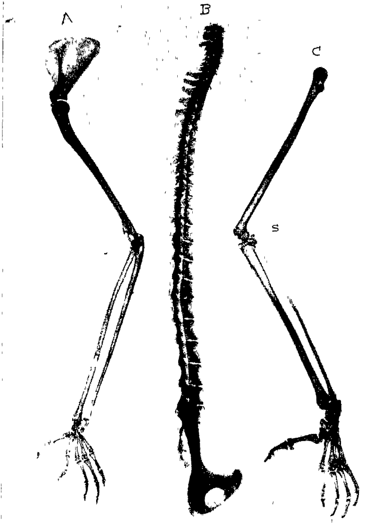
PLATE 1



The X-ray photograph of the entire skeleton.

PLATE 2



X-ray photographs A—Fore limb, B—Lateral view of the vertebral column; C—Hind limb Note in C the sesamoid S above the head of the fibula

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CONTRIBUTIONS TO OUR KNOWLEDGE OF THE ANATOMY OF THE LEMUROIDEA.

V. THE ORBIT OF LORIS LYDEKKERIANUS.

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AND

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INTRODUCTION.

Professors G Elliot-Smith (1), H H Woollard (2), Treacher-Collins (3) and Wood Jones (4) have related with inimitable clearness the structural changes observed in the eye of mammals which have taken to arboreal life, and emphasized the influence of the environment in the evolution of the visual organs Elliot-Smith has stated that "in the vast majority of living animals behaviour is dominated by smell or vision" In the mammals, according to the same author, both smell and vision get representation in the neopallium and in the arboreal animals visual sense becomes more powerful In acquiring this progressive dominance of visual over the olfactory organ, there have been induced in the related region of the arboreal animals profound anatomical changes In the lowly Prosimian, Loris lydekkerianus, the eyes have shifted from a lateral to a more forward position and "it is noteworthy that the changes in the inter-orbital region pendent on the shifting of the position of the eyes have sulted in a very marked reduction of the lachrymal bone". urther, the animal is truly nocturnal and it sleeps by day oth in captivity and in its natural surroundings) and shews ;ns of activity with the onset of dusk. Some of the habits the animal, such as the use of the fore-limbs in picking and carrying the food (banana slices, boiled rice mixed th milk and fresh crabs and prawns) to the mouth, its wer to grasp the branches of trees and its love of darkness e suggestive of a specialized organ of vision In this communication an account of the anatomy of the orbital region Loris lydekkerianus is offered.

BONY ARCHITECTURE OF THE ORBIT.

The various bones entering into the formation of the bital cavity have already been described in a previous mmunication (9). Briefly stated the roof is formed by the orbital plate of the frontal bone and the orbital portion of the pre-sphenoid The lateral wall is formed by the zygoma and its frontal and temporal processes The orbital plate of the maxilla, a part of the zygoma and the zygomatico-maxillary suture form the floor The medial wall is formed above by the frontal, below by the maxilla and in the middle-line from behind forwards by the pre-sphenoid above and to a small extent the vertical plate of the palatine below, by the os-anum (of the ethmoid) in the middle, and in front by the axillary process of the frontal above and the frontal process the maxilla below (Text Fig. 1)

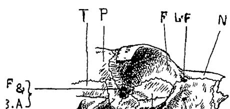

Fig. 1.

'igure showing the bones of the medial wall of the orbit

(Jugular bone has been detached)

-Frontal bone, L.F —Lachrymal foramen; I O F —Infra orbital foramen, M—Maxilla, N—Nasal bone, O P —Os planum, O.F. & F S A —Optic foramen and foramen lacerum anterius, P—Parietal bone, P A —Palatine bone, S P H.—Sphenoidal bone, T—Temporal bone

The margin of the orbit which is complete is formed by the frontal above, zygoma laterally and maxilla inferiorly whilst the apex is marked by the optic foramen and foramen lacerum anterius (Text Fig 2).

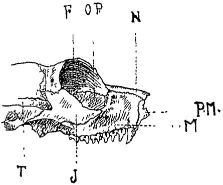

Fig. 2.

Lateral view of the bony orbit, showing the relations of the bones that go to form the orbital rim.

F—Frontal bone, J—Jugular bone; M—Maxilla; N—Nasal bone, P.M—Pre-maxilla; O.P.—Os planum, T—Temporal bone; P.M.—Pre-maxilla

The position of the lachrymal foramen outside the orbital cavity and the reduction of the supra-orbital foramen to a simple notch are noteworthy features.

The base is very nearly circular in outline and measures on an average 16 mm. along the horizontal and 17 mm. along the vertical diameter The depth of the orbital cavity is about 16 mm. The two orbital axes subtend an angle of about 50°.

EXTERNAL FEATURES OF THE ORBITAL REGION.

The large and prominent eyes of the animal are directed forwards (Text Fig 3) In the formalin preserved specimen the ramus palpebrarum measures 10--12 mm, the distance between the two inner canthi is about 7 mm No eyebrows as a distinct structure can be made out as the forehead and the face are very richly covered with soft fur.

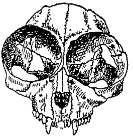

Fig. 3.

Frontal view of the skull showing the position of the orbits.

The upper eye-lid is relatively larger than the lower and the external margin of both lids bears a row of ciliae, the inner margin of both the lids is deeply pigmented and the two margins enclose a strip of space about one millimetre in breadth. Medially the pigment of the inner margin appears to fade abruptly and here the margin itself ends in a small rounded eminence to the inner and medial aspect of which is situated a hardly discernible puncta lachrymalis. The outer margin meets the inner slightly medial to this eminence, along the internal margin the openings of the tarsal glands are situated

There is a well-developed lacus lachrymalis between and medial to the puncta lachrymalis, but there is no caruncula At the medial commissure there is a well-formed plica semilunaris (Nictitating membrane) which possesses two horns which attach themselves to the conjunctival fornices The superior horn extends as far as the medial third of the superior fornix, whilst the inferior horn reaches the middle of the inferior fornix It is to be noted that when the eyes are wide open the nictitating membrane does not cover up any portion of the cornea and it does not appear to cover the cornea when there is normal movement of the eye-ball

The conjunctiva is a thin glistening membrane which consists as usual of a palpebral and a bulbar portion The palpebral conjunctiva is not pigmented except at the inner margin of the lid and it is so thin that the tarsal glands can be seen through its ocular surface as fine parallel striations The bulbar conjunctiva appears to be finely pigmented.

On reflecting the skin of the lids and circum-orbital region, it is observed that the superficial fascia is thin and does not seem to hold much fat On dissecting out the superficial fascia, the orbicularis oculi muscle and cutaneous vessels and nerves of the region become exposed (Text Fig 4)

The Orbicularis oculi is a thin broad circular sheet of muscle surrounding the entrance to the orbit, and the arrangement of its fibres is such that it can be stated to consist of an orbital part and a palpebral part The fibres of the orbital part are spread over a larger area with the result that this muscular sheet is relatively thinner than that of the palpebral part. The fibres of this muscle which have a concentric arrangement spread out laterally but crowd together medially to form a thick bundle Some of the peripheral fibres, however, appear to enter into relation with the adjacent muscles Some of the fibres on the medial aspect seem to be continuous with the quadratus labi superioris and frontalis, whilst on the inferior aspect they appear to merge with the Orbicularis oris, and laterally with the Orbito auricularis muscles—superior and inferior.

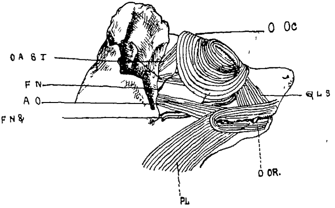

Fig. 4.

Figure to show the muscles of the orbital and circum-orbital region

A.O.—Auriculo-oris muscle, F N—Facial nerve, O A S I—Orbito-auricular superior and inferior muscle, O OR—Orbicularis oris, O OC—Orbicularis oculi, PL—Platysma, Q L S—Quadratus labi superioris

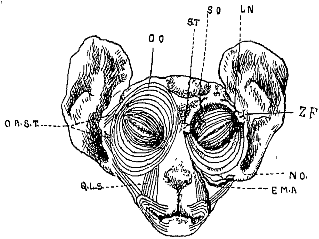

Fig. 5.

Figure showing the dissection of the circum-orbital region (Some vessels following the nerves have been omitted for the sake of clearness)

E M A—External maxillary artery, L.N—Lachrymal nerve, N O—Branch of facial nerve supplying orbicularis oculi, O O—Orbicularis oculi, Q L S—Quadratus labi superioris, O.A S I—Orbito-auricularis superior and inferior, S T—Supra trochlear nerve, S.O.—Supra orbital nerve, Z F—Zygomatico-facial branch of maxillary nerve

The outer fibres of the palpebral part are arranged in a manner similar to that of the orbital portion with which they blend to form a continuous sheet The inner fibres are arranged somewhat differently, whereas laterally the lower and upper fibres are continuous, medially they run together in a bundle, transversely beneath the fibres of the orbital part, to get inserted into the bony rim The branches of the facial nerve supply the orbicularis oculi muscle The other structures that are met with during the dissection of this part are the cutaneous nerves and vessels (Text Fig 5) Branches from the supra and infra trochlear nerves on the medial side, the supra orbital nerve above lachrymal and zygomatico-facial nerves laterally and infra orbital nerve on the inferior aspect are seen Each of these nerves is followed by a cutaneous branch of an artery of the same name

FASCIA IN RELATION TO THE ORBIT

Within the orbit the globe is surrounded and protected by three distinct and different fascial layers Of these, the outermost coat is the peri-orbital fascia which is the periosteum of the bony wall of the orbital cavity In front, around the orbital margin it is prolonged as a membranous septa (the orbital septa) and fills up the space between the bony orbital margin and the globe Centrally the orbital septa continues as a membranous sheet into the upper and lower lids Posteriorly where the bony walls are deficient the peri-orbital fascia is continued as a relatively tougher membrane to compensate for the deficiency of the bony wall Laterally the membrane is reinforced by some muscle fibres and forms the membrana Orbitalis Musculosa (Protractor bulbi) We do not know if this structure is present in Tarsius and Chimpanzee, in the human subject, however, this muscle is vestigial and is reduced to a thin narrow lamina and confined to the inferior orbital fissure (Whitnall).

The fat in the orbit not only forms a continuous covering of varying thickness beneath the peri-orbita, but also fills up the gaps between and deep to the muscles, and it thus forms a bed of adipose tissue for all the extrinsic structures of the orbit

The Capsule of Tenon (Fascia bulbi) which is in immediate relation to the globe consists of two layers enclosing a potential space between them. The deeper layer is attached to the sclera; while the superficial layer is prolonged on to and over the muscles Anteriorly the fascia is continued on to the conjunctival fornices, posteriorly it could be traced as far as the entrance of the optic nerve into the globe. The tendons of all the extrinsic muscles of the globe, *viz.*, the four recti, two obliques and one retractor, pierce the capsule of Tenon before being inserted into the sclera. In addition the ciliary vessels and nerves also pierce the capsule to enter the globe.

The Muscles of the Orbit —There are in all eight muscles within the orbit, of these the levator palpebræ superioris belongs to the upper eye-lid and the other seven constitute the extrinsic muscles proper of the eye-ball.

M. Levator palpebræ superioris arises from the roof of the orbit from a small area of the bone just in front of the optic foramen Its fleshy belly is rather thin and lies beneath the peri-osteum of the roof

This muscle covers the superior rectus muscle and its thin tendon expands as it proceeds anteriorly and divides into two lamellæ; the superior part is inserted into the orbital septum and the inferior or deeper lamellæ into the superior border of the upper tarsal plate. It should be stated that the muscle sheath undergoes some modification and becomes thickened to form a transverse band which laterally passes into the substance of the lachrymal gland, and medially runs towards the trochlea

This muscle is supplied by a branch of the superior division of the oculo-motor nerve which enters the ocular surface of the muscle.

M. Superior oblique is a slender muscle with a thin belly and a long tendon; it takes its origin from the bony area situated on the dorso-medial aspect of the optic foramen Whereas in the human orbit this muscle lies at the junction of the roof and the medial wall, in Loris lydekkerianus it lies more in relation with the medial wall, in this animal it partly covers and lies along the upper border of the medial rectus from which it is separated by the naso-ciliary nerve Its long tendon which is at first directed anteriorly, runs, after it passes through the trochlea, backwards and lateralwards, the reflected part as it proceeds further expands and approaches the tendon of the superior rectus to be inserted to the globe (behind the equator) about the medial border of the superior rectus

The trochlear nerve entering the superior surface of the muscle innervates it.

M Inferior obliquc has a relatively much better developed muscular belly than the superior oblique Of all the ocular muscles this is the only muscle that does not arise from near the apex of the orbit This muscle arises as a thick tendinous band from the maxilla, and its origin is situated about one millimetre behind the bony margin of the orbit and about one millimetre medial to the zygomatico-maxillary suture From its origin, the inferior oblique muscle proceeds backwards, lateralwards and slightly upwards, and passes beneath the inferior rectus which separates the inferior oblique from the globe in that *situation* On the lateral aspect of the globe, the muscle is reduced to a thin tendon which passes medialwards beneath the lateral rectus and gets inserted to the globe beneath the tendon of the lateral rectus and behind the equator The inferior division of the oculo-motor nerve enters the muscle at its posterior border and supplies it

The recti muscles are characterized by some common features They arise from a common tendinous ring (*the annulus tendineus Communis of Zinn*). and all of them are thin sheets of muscle whose tendons, after piercing the capsule of Tenon, are inserted into the globe in front of the equator The nerves enter the ocular surface of these muscles

M Superior rectus lies beneath the levator palpebræ superioris which separates the former from the roof of the orbit and the frontal nerve The fleshy belly of the muscle gives rise to a thin tendon which is inserted into the globe in front of the equator and 1 5 mm behind the limbus The superior division of the third nerve supplies this muscle

M Lateral rectus lies in the peri-orbital fat. A short distance from its origin, it covers the ciliary ganglion Anteriorly the tendon of inferior oblique muscle passes beneath the tendon of the lateral rectus separating the latter from the globe Near its insertion, the superior border of the tendon passes beneath the lateral part of the lachrymal gland This muscle is supplied by the abducent nerve

M Inferior rectus has a fairly well-developed belly ; anteriorly the muscle is separated from the floor of the orbit by the inferior oblique muscle The nerve supplying the inferior oblique muscle runs parallel to and in relation with the lateral border of the inferior rectus The inferior division of the third nerve supplies this muscle.

M Medial rectus is the largest of the four recti muscles, and it is separated along its entire extent, from the medial wall of the orbit by the superior oblique muscle and its tendon, from which the medial rectus is separated anteriorly by the naso-ciliary nerve The muscle is supplied by the inferior division of the third nerve

M Retractor bulbi which is in a retrogressive phase in Loris lydekkerianus arises at the apex of the orbit from the tendinous ring of Zinn, between the origins of the superior and lateral recti This muscle lies entirely within the cone of the recti muscles and under cover of the lateral rectus to some extent The retractor muscle is inserted into the globe by means of a short thick tendon between the superior and lateral recti muscles far behind the equator The muscle is supplied by a branch of the third nerve (See Fig. 6)

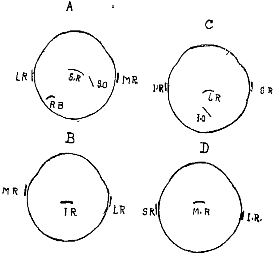

Fig. 6.

Diagram to show the positions of insertions of muscles to the eye-ball

A—Eye-ball as seen from above.
B— ,, ,, ,, from below
C— ,, ,, ,, from the lateral aspect
D— ,, ,, ,, from the medial aspect

I O.—Inferior oblique , I.R —Inferior rectus , L R —Lateral rectus , M R — Medial rectus , R.B —Retractor bulbi , S.O —Superior oblique , S R — Superior rectus.

In the following table details as regards insertion, etc, are noted :—

	Muscle	Breadth of insertion	Distance of the insertion from sclero-corneal junction
1	Superior rectus	3 0 mm	4 5 mm
2	Superior oblique	1 7 mm	5 2 mm
3	Medial rectus	2 7 mm	3 8 mm
4.	Inferior rectus	4 0 mm	5 0 mm
5	Inferior oblique	4 0 mm	9 3 mm
6	Lateral rectus	4 0 mm	5 2 mm
7	Retractor bulbi .. .	2 5 mm	8 5 mm.

NERVES.

The cutaneus nerves that supply the circum-orbital region and the lids have already been mentioned The nerves that are in relation to the orbit and supply the eye-ball and its muscles are the following ·—

(*a*) The optic nerve, (*b*) The ocular-motor nerve, (*c*) The trochlear, (*d*) Ophthalmic and maxillary divisions of the trigeminal, (*e*) Abducent nerve

With a view to make the relations of the nerves more comprehensive, in addition to their course in the orbital cavity, part of their intra-cranial course is also noted At the level of the cavernous sinus, the relationship of these nerves appears to be very similar to the conditions obtaining in the human subject. The internal carotid artery and the abducent nerve traverse the sinus, the nerve lying latero-inferiorly to the artery The other nerves are all related to the lateral wall of the sinus and are placed from above downwards in the following order the oculo-motor, the trochlear, ophthalmic and maxillary nerves At the anterior end of the sinus the trochlear nerve crosses the oculo-motor and becomes superficial to the latter

At the apex of the orbit. the relationship alters. The ophthalmic nerve is already divided into its three component branches—the frontal, the naso-ciliary, the lachrymal. The oculo-motor divides into superior and inferior divisions. The trochlear, frontal and lachrymal nerves do not pass through the annulus of Zinn

The relation of the structures at the entrance to the orbit is as follows —The frontal and the trochlear nerves pass external to the annulus and lie superficial to the proximal portion of the levator palpebræ superioris, the lachrymal also passes outside the ring and lies lateral to the levator-palpebræ superioris (Text Fig 7) In the centre of the ring is

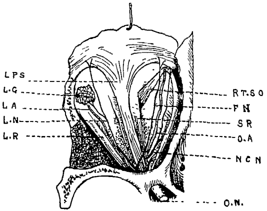

Fig. 7.

Dissection of the left orbit to show the structures as seen from above.

F.N.—Frontal nerve, L A —Lachrymal artery, L G.—Lachrymal gland, L N —Lachrymal nerve, L.P.S.—Levator palpebræ superioris; L R — Lateral rectus muscle, N.C.N —Naso-ciliary nerve, O.A —Ophthalmic artery, O N.—Optic nerve; R T.S.O.—Reflected tendon of superior oblique muscle, S R —Superior rectus muscle.

the optic nerve on the lateral aspect of which is the ophthalmic artery The superior and inferior divisions of the oculo-motor nerve both of which lie on the lateral aspect of the optic nerve are separated by the naso-ciliary nerve The abducent nerve also lies lateral to the optic nerve

The oculo-motor nerve supplies all the extrinsic muscles of the eye-ball with the exception of the lateral rectus and superior oblique muscles At the apex of the orbit, it is crossed by the trochlear nerve which now lies superficial to the oculo-motor, the nerve divides, not far from the apex, into two branches (Text Fig 8) The superior division after giving off a branch to the retractor bulbi muscle, enters the ocular surface of the superior rectus, and some of the branches after piercing through the superior rectus supply the levator palpebræ superioris muscle Similarly the inferior division of the nerve gives off a branch, which, accompanied by a branch of the ophthalmic artery, runs in the interval between the lateral rectus and the inferior rectus and innervates the inferior oblique muscle At a short distance from its origin the branch to the inferior oblique gives off a short thick root to the ciliary ganglion, and a short branch of the inferior division enters the proximal part of the ocular surface of the inferior rectus The branch of supply to the internal rectus passes medially beneath the optic nerve to enter the ocular surface of the muscle.

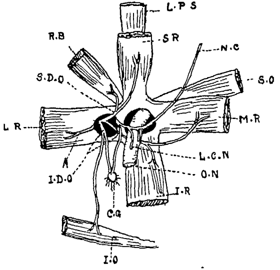

Fig. 8.

Diagram to show the muscles of the eye-ball and the structures in relation to the optic nerve.

C G —Ciliary ganglion, A—Abducent nerve, I D O —Inferior division of the oculo-motor nerve, I O —Inferior oblique muscle, I R.—Inferior rectus muscle, L.C.N —Long ciliary nerves, L.P S.—Levator palpebræ superioris muscle, L R —Lateral rectus muscle, M R —Medial rectus muscle, N C —Naso-ciliary nerve, O N —Optic nerve, R B —Retractor bulbi muscle, S O.—Superior oblique muscle, S R —Superior rectus muscle, S.D O —Superior division of the oculo-motor nerve.

The trochlear nerve lies, as has already been mentioned, in the lateral wall of the cavernous sinus and runs parallel to and below the third nerve. Behind the annulus of Zinn it crosses the oculo-motor nerve, it then runs, medially, obliquely across the superior rectus, and superficially, the origin of the levator palpebræ superioris, to enter the proximal part of the superficial surface of the superior oblique muscle. This nerve enters the orbit through the foramen lacerum anterius.

The ophthalmic and maxillary divisions of the trigeminal nerve.—The ophthalmic division of the fifth nerve divides at the anterior part of the cavernous sinus into three branches, *viz.*, the frontal, the naso-ciliary and the lachrymal nerves. The frontal nerve, which lies superficial to the annulus of Zinn, after crossing from the lateral to the medial side, the levator palpebræ superioris near its origin, proceeds, accompanied by the supra-orbital branch of the ophthalmic artery in the interval between the levator palpebræ superioris and the superior oblique. The main nerve after giving off the supra-trochlear branch behind the equator, runs straight as the supra-orbital and passes through the supra-orbital notch to supply the skin of the forehead and the upper eye-lid. The supra-trochlear branch crosses the reflected tendon of the superior oblique and leaves the orbit, after piercing through the orbital septum, on the medial side.

The naso-ciliary nerve which passes between the two divisions of the oculo-motor nerve, crosses from the lateral to the medial side, between the superior rectus and the optic nerve, and here it gives off long ciliary nerves and a branch of supply to the ciliary ganglion. It is continued between the superior oblique and the internal rectus where it divides into two branches, an anterior infra-trochlear and a medial ethmoidal; the former passes beneath the tendon of the superior oblique and pierces through the orbital septum to supply the skin on the medial aspect of the upper lid and the orbit.

The lachrymal nerve enters the orbit external to the annulus of Zinn between the lateral and superior recti muscles. After a short forward course it receives a branch of communication from the maxillary nerve and then divides into two branches—medial and lateral—which proceed to supply the lachrymal gland. A branch from the medial division (and very rarely from the lateral division) pierces through the zygomatic process of the frontal bone and supplies the skin over the upper eye-lid.

The abducent nerve lies infero-lateral to the internal carotid artery in the cavernous sinus; at the apex of the orbit the nerve passes through the annulus of Zinn on to the ocular surface of the lateral rectus which it supplies

The optic nerve which runs medio-laterally enters the orbital cavity through the optic foramen Its course within the orbit extends over a space of about 7 mm and it enters the globe slightly medial to the posterior pole. The cross section of the nerve is nearly oval

The relations of the optic nerve (see Fig. 8) —Superiorly are the ophthalmic artery which crosses the optic nerve from the lateral to the medial aspect, and the frontal and naso-ciliary nerves Laterally the artery which lies next to the nerve separates the latter from the abducent and the inferior division of the oculo-motor nerve Slightly anteriorly the ciliary ganglion lies lateral to the nerve, under cover of the lateral rectus. Inferiorly the nerve to the medial rectus crosses the optic nerve The short ciliary nerves very nearly surround the optic nerve

The maxillary nerve though not connected with the eye is described here as it has an intra-orbital course It enters the orbit through the foramen lacerum anterius, external to the annulus of Zinn (Text Fig 9). The nerve lies on the floor of the orbit beneath the *inferior rectus*, and about the middle of the floor passes into the infra-orbital canal Within the orbit it gives off a zygomatico-facial branch which runs between the *lateral* and *inferior recti* muscles and one branch of this nerve establishes, as noted above, communication with the lachrymal nerve. From the nerve the posterior superior alveolar branch is also given off The main stem of the nerve leaves the orbit through the infra-orbital foramen.

The ciliary ganglion (see Fig. 9) is of fairly large size and is about the size of a pin's head, it lies under cover of the lateral rectus on the lateral side of the optic nerve It receives two roots—one from the oculo-motor and the other from the naso-ciliary—both of which enter the ganglion on its posterior aspect From the anterior aspect of the ganglion very fine branches—short ciliary nerves, about 8–10 in number —proceed, some on the superior and some on the inferior aspect of the optic nerve and pierce the sclera around the entrance of the optic nerve and enter the eye-ball.

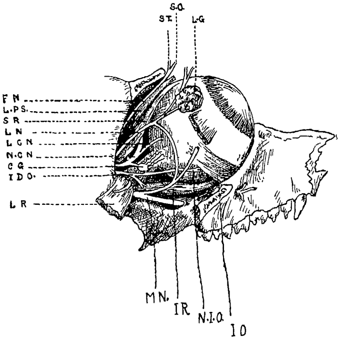

Fig. 9.

Dissection of the right orbit to show the structures as seen from the lateral aspect.

C G.—Ciliary ganglion, F N —Frontal nerve, I.D.O —Inferior division of the oculo-motor nerve, I O —Inferior oblique muscle, I.R —Inferior rectus muscle, L C N —Long ciliary nerve, L.G.—Lachrymal gland, L N —Lachrymal nerve, L P S —Levator *palpebræ superioris* muscle, L R.—Lateral rectus muscle, M N —Maxillary nerve; N.C.N —Naso-ciliary nerve, N.I O —Nerve to inferior oblique muscle, S.O.—Supra-orbital nerve, S R.—Superior rectus muscle, S T —Supra-trochlear nerve.

THE ARTERIES.

The main arterial supply to the orbit and its contents is from the ophthalmic artery—a branch of the internal carotid artery It arises from the carotid at the apex of the cavernous sinus and enters the orbit through the optic foramen in company with the optic nerve Here the artery lies slightly on the latero-inferior aspect of the nerve ; in the orbit, the artery crosses the nerve from the lateral to the medial aspect, proceeds towards the medial angle of the orbit, and gives off the following branches —

(*a*) *The central artery of the retina* —On sectioning the optic nerve it is found that this artery is situated about the axis of the nerve, in this respect Loris lydekkerianus resembles Tarsius but differs from Chimpanzee in which no central artery of the retina has been described

(*b*) *The supra-orbital branch* runs anteriorly between the roof of the orbit and the *Levator palpebræ superioris*, along with the frontal nerve

(*c*) *The lachrymal artery* follows the course of the nerve bearing the same name and supplies branches to the lachrymal gland and one of its terminal branches passes out through the foramen on to the lateral aspect of the orbit.

(*d*) *The ciliary arteries* —There are two branches which follow the long ciliary nerves, the other branches, *viz.*, short ciliary branches, take origin either from the ophthalmic artery or from its branches and pierce the globe around the entrance of the optic nerve.

In addition to the above-mentioned branches, the ophthalmic artery supplies the orbital muscles.

The lachrymal apparatus consists of the secretory lachrymal glands and excretory passages which include lachrymal canaliculi, lachrymal sac and naso-lachrymal duct The lachrymal gland which is situated on the lateral aspect of the orbit under cover of the zygoma, consists of superior and inferior portions separated by the aponeurotic expansion of levator palpebræ superioris It is a small lobulated gland measuring 3 to 4 mm in breadth, 2 to 3 mm in length and 2 to 3 mm in thickness Its arterial supply is derived from the lachrymal branch of the ophthalmic artery and the nerve supply is from the lachrymal branch of the ophthalmic division of the fifth nerve The nerve divides into three or four branches before entering the gland Further the main nerve receives a twig from the maxillary division of the trigeminal nerve

From the anterior aspect of the gland two or three ducts emerge which pass through the peri-orbital fat and open into the lateral aspect of the superior fornix

The lachrymal canaliculi—superior and inferior—commence as funnel-shaped depressions, the bases of which correspond to the puncta The puncta are situated at the medial ends of the margins of the lids and are not visible on a superficial examination On slightly everting the lid, and pushing medially the fleshy mass which overhangs the puncta on their medial aspect, they become visible. Each canaliculus runs medially "in the thickness of the lachrymal part of the lid margin behind the medial commissure" to enter the lachrymal sac.

The lachrymal sac lies behind the medial palpebral ligament and outside the brim of the bony orbit From the lower end of the sac starts the naso-lachrymal duct, which runs downwards to open into the inferior meatus under cover of the maxillo-turbinal It may be of interest to note here that although there is a well-formed lachrymal gland we have not seen the animal shed tears

The Globe occupies the roomiest part of the orbital cavity, *viz.*, the anterior part of the cavity. As in other mammals, it is nearly spherical in shape though made up of segments of two unequal spheres, the posterior of which is bigger than the anterior which corresponds to the corneal hemisphere. The posterior surface of the posterior segment is rather flat and thus renders the globe apparently hypermetropic The antero-posterior diameter of the globe is about 15 mm. and the lateral and vertical diameters are equal and measure about 14 mm. The two optic axes subtend an angle of about 26° between them.

The globe is nowhere in contact with the bony orbit but is separated from it by muscles, fascia, vessels and nerves The structures in relation to the globe have already been described It may, however, be stated here that the optic nerve enters the globe slightly medial to its posterior pole, the short ciliary nerves enter the globe very near the entrance of the optic nerve. There are four venæ verticose in the usual position emerging from the globe slightly behind the equator and lying in relation to the posterior segment of the globe. The four recti lying in the vertical and horizontal planes are in close relation to the globe The relations of the retractor, protractor, the obliques, and of Tenon's capsule to the globe have already been described

The cornea is relatively large, and even when the palpebral fissure is widely open the sclera is not visible It is a known fact that in monocular field of vision large corneal surface plays an important part. In the following table the dimensions of the cornea with reference to those of the eye-ball of some of the mammals are given :—

Animal	Dimensions of the eye-ball		Dimensions of the cornea		$\frac{D\,C}{D\,E}$
	Antero-Posterior	Lateral	Lateral	Vertical	
Loris lydekkerianus	15	14	12.5		83
*Man	24.8	24.4	11.6	11	47
*Rhesus Monkey	19.5	19	12	11	62
*Cat	22	21	18		82
*Horse	44	54	34	27	78
*Sheep	36	38	27	22	78
*Rabbit	16	20	15		94

* From Treacher-Collins.

From the above table it will be seen that man and monkey possess a comparatively small cornea and Loris lydekkerianus stands midway between the rabbit and the cat as regards the relative size of the cornea.

The iris which is greyish brown to brown in colour exhibits a well-marked pattern The shape of the pupil varies with the extent of contraction of the iris When fully dilated the pupil is oval, when it is half-contracted the pupil is oval with its long axis in the vertical plane, and when it is fully contracted the pupil is acutely oval with its long axis in the vertical plane and its upper end inclined slightly medially Loris lydekkerianus possesses a well-developed ciliary muscle.

In Loris, associated with the large cornea, there is a large very nearly spherical lens the lateral diameter of which is slightly greater than its antero-posterior. Relatively to the size of the eye-ball the lens is rather large. These facts are brought out very forcibly by a critical examination of the following table :—

Diameter of the lens in some Mammals

Animal	Antero-posterior Diameter A	Lateral B	$\frac{A}{B}$
Loris lydekkerianus	6.5	7.5	86
(Formalin fixed)	6.8	8	85
*Man	4.5	9	5
*Chimpanzee	4	7	57
*Monkey	3.5	6	58
*Civet Cat	5	6.5	77
*Horse	11	20	55
*Sheep	10	12.5	8
*Rabbit	7	9	78

* From Treacher-Collins

The relation of the size of the lens to that of the eye-ball —

Loris lydekkerianus	10.5 to 100
*Man	42 to 100
*Cat	10 to 100
*Rabbit	8 to 100
*Sheep	7.6 to 100
*Horse	6 to 100

* From Emmert quoted by Treacher-Collins

It is to be noted here that due to the relatively large size of the lens, the circumlental space is very much reduced and macroscopically the lens seems to be in apposition with the ciliary body in formalin fixed eyes.

On macroscopic examination it is seen that the ciliary muscle is well developed and the plicæ of this muscle are well marked. The retina extends to very near the muscle. Consistent with the nocturnal habits of this animal, the tapetal layer is well formed Primates This layer has a golden yellow colour and is closely attached to the inner surface of the choroid coat of the eye

The anterior chamber which is relatively deep measures about 3.5 mm, and the vitreous chamber is about 4.5 mm. (from the posterior surface of the lens to the anterior surface of the retina) The vitreous chamber is bound by a distinct and delicate hyaloid membrane. We could not make out the presence of a hyaloid artery.

DISCUSSION.

A. From the foregoing description of the Orbit of Loris lydekkerianus it will have become obvious that the conditions in this animal are somewhat different from those described by Professor Wood Jones. Taking the bony architecture of the orbit into consideration, it is seen that in Loris lydekkerianus there is the 'OS-planum' forming part of the medial wall of the orbit.

The Os-planum forming the inner wall of the orbital cavity is maintained by Meckel to be characteristic of the human skull. Cuvier identified this part of the skull in monkeys and declared that "the Os-planum of the ethmoid was, in Lemurs, altogether enveloped by the frontal and the palatine, and therefore did not appear as an element in the wall of the orbit". Both Grandidier and Milne Edwards deny the ethmoidal contribution to the orbital wall as they consider the Os-planum is overlain by the frontal which directly comes into contact with the maxilla Flower (5) in dealing with the osteology of the Lemurs states as follows — "In the common lemur . the Os-planum of the ethmoidal does not enter into the inner wall of the orbit but is shut out from it by the maxilla as in most inferior mammals." Kostlin, according to Forsyth Major, is the only predecessor of his who has given "some positive and on the whole fairly correct information on the Os-planum"; and Forsyth Major (6a) in his paper on "Some Characters of the Skull in the Lemur and Monkeys" states that "amongst the Malagasy lemurs a fairly large Os-planum (of the ethmoid) is present in all the species of Microcebus In the other genera the planum becomes fused with the palatal at a very early date. But distinct small Os-planum is often visible in young specimens of Hapalolemur, Chirogale, Lepidolemur and Avahis and sometimes in Lemur"; and the same author in another paper (6b) writes that "the lateral part of the Os-planum (of the ethmoid) has become united with the palatal at a very early stage; a remnant of the suture with the latter bone is seen in the adult at its antero-medial extremity, in exceptional cases, e g, *Lemur catta* and young specimens of Lepido-lemur, the planum remains completely or almost completely distinct from the palatal." Thus the credit of having established that the Os-planum generally forms part of the orbit of Lemurs must belong to Forsyth Major. Duckworth (7) who agrees with Forsyth Major finds an Os-planum and describes the orbital region of the Lemur as follows :—"On the inner orbital wall the frontal and maxillary bones join along a suture for a distance of about 5 mm and thus widely separate the ethmoidal from the lachrymal bone "

From the preceding paragraphs it is abundantly clear that there is wide divergence of opinion as regards the presence of the Os-planum in the Lemurs

This uncertain state as regards the Os-planum which has been literally the bone of contention for the last two hundred years, led Wood Jones to study afresh the orbito-temporal region of the skull of the Lemur After an examination of the specimens described by Forsyth Major he came to the conclusion that the description of the adult skulls by many of the previous investigators was not only defective but the identification of the *Os-planum* was of doubtful value. Hence he studied the skulls of two full-term fœtuses (L catta and a hybrid L albifrons X L Melanocephala) and generalized that "in the *lemur skulls* the Os-planum of *the ethmoid is lacking and a very common mammalian but definitely non-primate arrangement of the bony element is present in this region.*" In arriving at this conclusion Wood Jones quotes Forsyth Major who says that "it (the so-called Os-planum of the ethmoid) always forms the roof of the pneumatic cavity which often (L catta , L. macaco , L. various) is but an appendix of the maxillary sinus The anterior portion of the palatal also participates as a rule in the formation of this cavity by forming its posterior cul-de-sac " Wood Jones further states that "it is the variability of the posterior extension of this inflated area that produces the variability of the presumed suture line The bones of the orbital wall are particularly thin and transparent in the lemurs and in the adult examples the septa between air chambers may be far more conspicuous than the actual suture lines."

As against the description of Wood Jones the statement of Forsyth Major—' the early union of palate bone with the planum renders it difficult to state for every genus and every species, where no young stages were available and where no sections could be made of the skull, in what degree, if at all, the palatal partakes in the formation of the walls of the pneumatic caviaty' must be quoted. In all the Ethiopian and Oriental lemurs, according to Forsyth Major, there is a distinct Os-planum and the orbital process of the palate is small, and in the Malagasy lemurs "part of the planum is shielded by the frontal, and the anterior prolongation of the orbital process is large. In these animals the larger portion of the orbital process is part of the planum which in union with a small process of the palatal helps to form the walls of a pneumatic cavity " It is thus obvious that Forsyth Major does not preclude the possibility of the involvement of the planum in the constitution of the bony wall of the air sinus. In so far as it concerns Loris lydekkerianus we are satisfied that there has been no mistake in differentiating between the septal walls and the sutures , and in all the skulls examined by us (both new-born and adult) there was no such fusion as is referred to by Forsyth Major between planum and the palatal , and the constituent bones of the region could easily be dis-articulated Further it should be stated that in L lydekkerianus there are no obvious air sinuses in the suture line between the Os-planum and the vertical plate of the palatal bone.

Wood Jones describes the orbital wall of the fœtal *Lemur catta* as follows —"The orbital plate of the frontal takes a very large share in the formation of the orbital wall ; it meets the nasal and the lachrymal in front, but at this stage it is separated from the frontal process of the maxilla by an unossified interval Behind it meets the parietal at the coronary suture, and below it meets the anterior edge of the very small orbito-sphenoid. Along the lower border of the orbital plate of the frontal runs an elongated bone shaped somewhat like a plough-share This bone articulates in front with the lachrymal and behind with the orbital plate of the frontal ; it is in contact with the orbito-sphenoid and ali-sphenoid Below greater portion of it is free, but in front, the maxillary which is very small and only partially ossified meets its lower border. This long bone is the orbital process of the palate and about its mid-point is perforated by two foramina presumably the naso-palatine canals "

From a study of the above description it is easy to see that the "orbital process of the palate" of Wood Jones is really the Os-planum correctly identified by Kostlin, Forsyth Major and Duckworth. In the late fœtal skulls of Loris lydekkerianus we have found definite evidence of suture lines separating the Os-planum. Further the fronto-maxillary suture the presence of which is denied by Wood Jones in L. catta, is very easily recognizable in L. lydekkerianus Moreover, the contention of Wood Jones that "the maxilla is excluded by the jugal from forming part of the margin" in Lemurs is untenable since the bony margin of the orbit in Loris lydekkerianus is formed by the frontal, the maxilla and the jugal

The lachrymal does not form part of the orbit in Loris lydekkerianus an observation which confirms the statement, as regards the condition in Loris and Nycticebus, of Forsyth Major. This disappearance of the lachrymal bone from the orbit is probably due, as maintained by Gregory (8), to the great reduction of the snout, of the extent of the nasal cavity and the shifting of the eyes from the lateral to a more forward position.

B The visual organ of Loris lydekkerianus presents a happy combination of obviously primitive and progressive features. An examination of the anatomical details suggests that though the structures which help the monocular field of vision persist, yet very definite changes which would favour binocular field of vision are observable.

In all those animals whose visual organs are suited most for monocular field of vision which, as is well known, aims at increased field of vision and clearness of peripheral images the eyes are set most prominently in the head and the size of the cornea relatively to the eye-ball is large. Further these animals have a large spherical lens with, in some instances, an oval cornea and oval pupil

In Loris lydekkerianus the complete bony orbital ring holds the eye fairly prominently, and as the diameter of the cornea is more than three-fourths the antero-posterior diameter of the globe the "white of the eye" is not exposed to view This animal possesses a nearly spherical lens whose lateral diameter is only slightly greater than that of its antero-posterior diameter. In addition to these and in a way more important is the presence of two antagonistic muscles—the retractor bulbi and the muscle of Gagenbaur The function of the R bulbi is to protrude the eyes and thereby secure temporarily an extension of the monocular field of vision. It should be stated that in lower animals the retractor bulbi is a powerful cone-shaped muscle having an extensive insertion as an antecedent to effective functioning, and in them the muscle of Gagenbaur is also well developed. But in Loris these two muscles are already in a retrogressive phase inasmuch as the *retractor bulbi is reduced to a thick bundle of muscle fibres with a small area of insertion and the* *protractor muscle to a relatively thin sheet* with scarcely a few muscle fibres.

Thus we find that when the palpebral fissure is wide the eyes are only slightly protruded, a phenomenon due to the co-ordinate action of Levator palpebrarum, and the muscle of Muller.

In Loris lydekkerianus there is a well-developed nictitating membrane which moves over the corneal surface especially when the eye-ball is drawn back by the retractor bulbi and which "protects the front of the eye from injurious influences, lubricates its surface and removes any foreign substance which may become lodged in it" (Treacher-Collins). Although this animal is perfectly arboreal and uses its forelimbs in grasping and carrying its food to the mouth, yet it has perfectly well-developed nictitating membrane In our dissections the presence of the Harderian gland could not be made out.

In Loris lydekkerianus the snout has become very much reduced and the eyes are directed forwards with the result that the two visual fields overlap to some extent The orbital axes subtend an angle of nearly 50° between them and each optic axis inclined to the median line at an angle of 13°. These circumstances are suggestive of the possession of binocular vision by this animal, and yet owing to the absence of a macula as the ophthalmoscopic examination reveals, the power of binocular vision must indeed be very limited It is likely that in this animal the anatomical defect—the lack of a fully formed macula with a fovea is compensated for by the movements of the head assisted by a restricted and yet observable conjugate movements of the eyes in the vertical plane.

We are indebted to Mr. K. Somasundaram for assistance in the preparation of the illustrations and our thanks are due to Prof. C. R Narayan Rao for help with literature.

SUMMARY.

The orbits are directed forwards. The presence of an Os-planum forming the inner wall of the orbit is noted. There is an easily recognizable fronto-maxillary suture. Maxilla is not excluded by the Jugal from forming part of the orbital margin. Evidence is brought forward to show that the animal possesses both monocular and binocular vision. Both Retractor bulbi and Protractor bulbi muscles are present. There is a tapetal layer A macula with fovea is lacking.

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AN EFFICIENT INSULATING DEVICE FOR ELECTROSTATIC WORK.

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In the case of Electrostatic instruments, especially instruments used in connection with atmospheric electricity, one of the most troublesome problems has been to secure good insulation Various materials, such as vulcanite, sulphur, amber, amberoid, etc , have been used with more or less success under different conditions. After a series of tests, I found that quartz, if kept warm, *i.e.*, at a temperature some degrees higher than the surroundings, was an extremely satisfactory insulator, and this has been used by me for some years past.* Leakage (apart from that through the slightly ionised atmospheric air) when it occurs through the supports, may be attributed to two distinct processes: firstly, conduction through the body of the dielectric and secondly, conduction along a surface film, essentially of moisture The first, *viz*, conduction through the body, is very little at ordinary temperatures. The second cause is responsible for most of the leakage, and in moist weather may cause a breakdown of the insulation. By warming the insulator, *i.e.*, maintaining it at some degrees above the surroundings, the formation of the film can be checked, with considerable improvement in the insulation The temperature should, however, not be too high, as it may increase the body conductivity appreciably and thereby fail to yield the full benefit of the removal of the film In fact, it has been found by trial that there is an optimum degree of warming which gives the best result. The warming may be carried out by means of an electric current, and by determining the rates of leak with different heating currents, the optimum current can be found (Table 1).

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* *Vide* description in *Indian Journal of Physics*, Vol. V, Part VII, pp. 759-60.

TABLE 1.

Readings of Gold Leaf Electrometer (charged to 130 *volts and isolated) after steady condition is reached, with different heating currents*

[*Instrument as in Fig.* 2(*a*)]

Heating currents in amps	Time in minutes					
	0	1	2	3	4	5
0	154	140	129	119	110½	102
1	154	141½	132	122½	114½	107½
15	154	145	136½	130½	124½	114
2	154	147	142½	137	130	127
3	154	150½	146½	143	138	135
4	**154**	**150**	**147**	**145**	**140½**	**137½**
5	154	150	146	143	139½	136
6	154	147½	143½	139	134	129
7	154	145	138	131	126	121

13th June 1932 Weather fairly cloudy
The optimum current can be seen to be about 4 amps

The above statements are true for most insulators, but in the case of glass, it is found that the body conductivity increases so rapidly with temperature that improvement of insulation by heating is very limited. Conditions are better with vulcanite, and considerable improvement in its behaviour even in moist weather could be secured by warming. But the slight softening which results by heating causes deformation, and this renders it unsuitable for use in many cases These defects are entirely absent in quartz whose body conductivity increases but slowly with temperature, and which retains its strength and hardly undergoes any expansion It is also a material which can be obtained reasonably cheap in the form required, *viz.*, tubes of diameters one to two cm. Quartz is now being employed by me successfully in a variety of appliances, and below are given some of the designs.

1. *Insulation for Quadrant Electrometer* (Fig 1).—

The vertical brass tube AB which carries the Electrometer head is in two parts, rigidly connected by means of a quartz tube Q As direct warming is out of the question, a glass tube T is fixed outside, concentric with the brass and quartz tube, and a heating coil C is wound over it. The heat

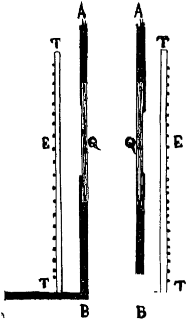

Fig. 1.

Insulation for Quadrant Electrometer.

AB.—Brass tube, QQ—Quartz tube, TT.—Concentric glass tube; EE.—Heating coil wound on glass tube.

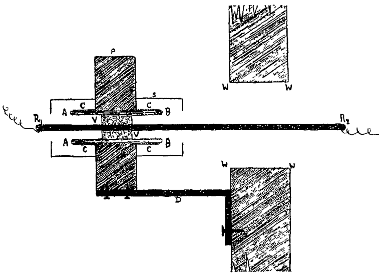

Fig. 2.*

Shackle and Tension Insulator.

D—Bracket, P—Plank screwed to bracket, AB—Quartz tube fixed into the plank; CC—Heating coil; V—Vulcanite plug, $R_1 R_2$—Thin metal rod passing tightly through V, S—Shield for protection against rain, etc, if necessary; W—Wall beyond which the insulated rod can project

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* Fig 2 represents the form of insulator used (i) for supporting the dissipating wire on either side in measurements of atmospheric electric conductivity, and (ii) to connect the collector to the recording electrometer across the wall or partition

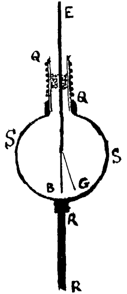

Fig. 2(a).

Electrometer of Gold Leaf type
(Cylindrical case and radial leaf.)

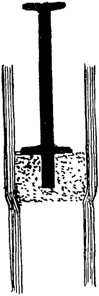

Fig. 2(b).

Design of an Insulating Support.

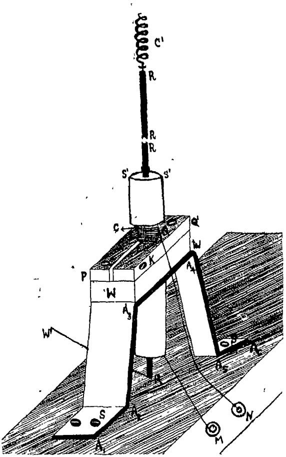

Fig 3 (a).

Mount for Radium Collector External View.

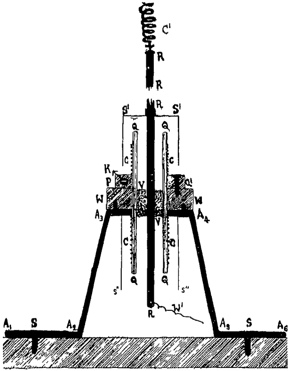

Fig. 3 (b).

Mount for Radium Collector Sectional View.

A_1......A_6—Bracket; WW—Plank screwed to bracket; QQ—Quartz tube passing through the centre of WW and A_3A_4; PQ′—Piece of wood fixed to WW to be tightened on QQ by means of screw K [Horizontal section shown in 3 (*c*)], CC—Heating Coil, RR—Metal rod of required height and projecting above, about 2″ below A_3A_4, C′—Collector, W′—Wire from collector, S′S′ & S″S″—Sleeve covers to protect QQ from rain, etc

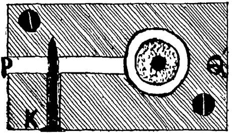

Fig. 3 (c).

Horizontal Section of PQ′

NOTE ON A CRITERION TO TEST WHETHER A GIVEN SOLUTION OF THE DIFFERENTIAL EQUATION $\phi\left(x, y, \frac{dy}{dx}\right)=0$ IS SINGULAR OR NOT.

BY DR. C N. SRINIVASIENGAR, D.SC.
(Department of Mathematics, Central College, Bangalore.)

§1. An elegant theorem to test whether or not a given solution of the differential equation $\phi(x, y, p)=0$ is included in the complete primitive as a particular solution (or part of a particular solution) was given by M. J. M Hill in a paper published in the *Proceedings of the London Mathematical Society*, Series II, Vol 17. We shall enunciate Hill's Theorem in an improved form as follows :—

The necessary and sufficient conditions that any analytic function $\psi(x, y)=0$ *should be a singular solution of the differential equation corresponding to the primitive* $c=g(x, y)$ *are—*

(i) $\displaystyle \operatorname*{Lt}_{\psi \to 0} \frac{\partial(\psi, g)}{\partial(x, y)} \neq 0$

(ii) $\displaystyle \frac{\partial\psi}{\partial x} \Big/ \frac{\partial\psi}{\partial y} = \operatorname*{Lt.}_{\psi \to 0} \left(\frac{\partial g}{\partial x} \Big/ \frac{\partial g}{\partial y}\right)$

assuming that the following conditions are fulfilled :

(a) *g does not become infinite when* $\psi=0$ *(but* $\frac{\partial g}{\partial x}$ *or* $\frac{\partial g}{\partial y}$ *may become infinite when* $\psi=0$*)*

(b) *all the values of x and y which make* $\psi(x, y)=0$ *do not also make* $\frac{\partial\psi}{\partial x}$ *and* $\frac{\partial\psi}{\partial y}$ *zero at the same time.*

Of the conditions (i) and (ii), (ii) denotes the condition that $\psi=0$ should be a solution ; (i) is the condition that it should be singular.

When the condition (a) is not satisfied, the primitive can be replaced by $c' = \dfrac{1}{g(x, y)}$.

One simple result can be formally proved as a corollary of the above theorem :

If $\psi(x, y) = 0$ *is a singular solution, it will continue to be singular when* x *and* y *are transformed by the substitutions* $x = f_1(X, Y)$; $y = f_2(X, Y)$ *where none of the first partial derivatives of* f_1 *or* f_2 *becomes infinite in virtue of* $\psi = 0$.

This follows from the identity—

$$\frac{\partial\{g(f_1, f_2),\ \psi(f_1, f_2)\}}{\partial(X, Y)} = \frac{\partial(g, \psi)}{\partial(x, y)} \cdot \frac{\partial(f_1, f_2)}{\partial(X, Y)}$$

§2. We shall discuss some interesting examples :—

(1) The primitive of $p = y(\log y)^2$ is given by $c = x + \dfrac{1}{\log y}$. Consider the solution $y \to +0 \equiv \psi(x, y)$

$$\underset{y \to +0}{\text{Lt.}} \frac{\partial(\psi, g)}{\partial(x, y)} = \underset{y \to +0}{\text{Lt.}} \begin{vmatrix} 0 & 1 \\ 1 & \dfrac{-1}{y(\log y)^2} \end{vmatrix} = -1.$$

$y \to +0$, which is evidently a solution, is therefore a singular solution

(2) $2p + y^3 e^{-\frac{1}{y^2}} = 0$, whose primitive is $y^{-2} = \log(c + x)$, or $c = e^{\frac{1}{y^2}} - x$.

$y = 0$ is a solution, but $y = 0$ makes $e^{\frac{1}{y^2}} - x$ infinite. If we take the primitive as $c = \dfrac{1}{e^{\frac{1}{y^2}} - x}$,

$$\underset{\psi \to 0}{\text{Lt.}} \frac{\partial(g, \psi)}{\partial(x, y)} = \underset{y \to 0}{\text{Lt}} \frac{1}{\left(e^{\frac{1}{y^2}} - x\right)^2} \cdot \left(\frac{o \,.\, e^{\frac{1}{y^2}}}{y^3} - 1\right)$$

$$= \underset{y \to 0}{\text{Lt.}} \left(\frac{0}{y^3\left(e^{\frac{1}{y^2}} - x\right)}\right)\left(\frac{e^{\frac{1}{y^2}}}{(e^{\frac{1}{y^2}} - x)}\right)$$

$$= 0.$$

$y=0$ is thus a particular solution. It should be considered as the limiting form of the primitive $c = \dfrac{1}{e^{\frac{1}{y^2}} - x}$ when $c \to \infty$. In the nomenclature of Professor E. B Wilson,* it may be called an "infinite solution"—a nomenclature of some use when dealing with equations of the second and higher orders

In this and in similar examples, where the determination of the limit of $\dfrac{\partial(g, \psi)}{\partial(x, y)}$ is troublesome, the following rule will be often helpful:

"*If* $\psi(x, y) = 0$ *is a solution of the differential equation, and if the curve* $\psi = 0$ *touches all the curves of the primitive at the same fixed points,* $\psi = 0$ *cannot be a singular solution.*"

This follows from a theorem discussed elsewhere:†

Any singular solution of the differential equation $\phi\left(x, y, \dfrac{dy}{dx}\right) = 0$ must necessarily represent the envelope of the primitive curves, and hence *at every point* on it must touch some one of the primitive curves (*Note:* A singular solution is defined as a solution not included in the primitive. This theorem will not be true when other definitions are adopted.)

(3) $p=y^2 \ e^{-\frac{1}{y}}$ has for its primitive $x + e^{\frac{1}{y}} = c$ $y \to +0$ is an asymptote of every curve of the family It is therefore a particular solution, or an infinite solution.

(4) $p=y \log y$. Primitive: $c = \log \log \left(\frac{1}{y}\right) - x$. The solution $y \to +0$ is an infinite solution for the same reason as in (3).

(5) A similar example. $p = \sec x \tan x$
Primitive: $y + c = \sec x$
Infinite solution: $x = \dfrac{\pi}{2}$.

(6) To discuss the nature of the solutions $y = \pm i$ for the equation $\dfrac{dy}{dx} = 1 + y^2$.

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* *Advanced Calculus*, §101.

† *Tohoku Mathematical Journal*, Vol 30, p. 376.

If we write the primitive in the form $y = \tan(x + c)$, or $x + c = \text{arc}\tan y$, the rule given in §1 will indicate that the solutions $y = \pm i$ are *not* included in this primitive We shall however be wrong, if we conclude on this ground that the solutions are singular, for they do not envelope the system of primitive curves. In fact, the conditions for Cauchy's existence-theorem being satisfied in any ordinary neighbourhood of the set of values $x = x_0$, $y = \pm i$, there can be only one solution satisfying the differential equation, assuming the value $y = \pm i$ when $x = x_0$. This solution is obviously $y = \pm i$ itself. These arguments clearly point out that these solutions are only particular integrals.

The fact is that $y = \tan(x + c)$ should be regarded as an *incomplete primitive*, for when we integrate both sides of the equation $\frac{dy}{1+y^2} = dx$, we tacitly omit the case when $1+y^2=0$. The equation $1+y^2=0$ should be regarded as a *residue* to the primitive in the above form That $y = \pm i$ are particular solutions may be brought into vividness when we take the primitive in the form $\frac{1+iy}{1-iy} = c\,e^{2ix}$.

I shall have occasion in other papers to consider many instances of such incomplete primitives The present example is a rare instance of its kind for equations of the first order.

§3. We shall next discuss the further criteria which enable us to decide about the character of the solutions in those cases where the condition (*b*) of §1 does not hold

If $\frac{\partial\psi}{\partial y}$ is *identically* zero $\left(\frac{\partial\psi}{\partial x}\text{ being not zero}\right)$, in other words, if ψ is a function of x only, the conditions as stated in §1 require no modification. In fact, if $\psi = 0$ is a solution, it is necessarily singular, unless g is also a function of x only, or contains ψ as a factor. Similar remarks hold good if $\frac{\partial\psi}{\partial x}$ is *identically* zero.

Hill has given examples where $\frac{\partial\psi}{\partial x}$ or $\frac{\partial\psi}{\partial y}$ vanishes, not identically but in virtue of $\psi = 0$. He has further proved that, if when $\psi = 0$, one of the two, $\frac{\partial\psi}{\partial x}$ or $\frac{\partial\psi}{\partial y}$, vanish, the other also vanishes and the relation $\frac{\partial^2\psi}{\partial x^2}\frac{\partial^2\psi}{\partial y^2} - \left(\frac{\partial^2\psi}{\partial x\partial y}\right)^2 = 0$ holds good. $\psi=0$, as it is, does not represent a proper curve.

Let now $\psi\,(x, y)=0$ be a function of this nature. Then, we have ·

The necessary and sufficient conditions that $\psi\,(x, y) = 0$ should represent a singular solution of the differential equation corresponding to the general primitive $c = g\,(x, y)$ are ·

(i) *One at least of the limits*

$$\underset{\psi\to 0}{\text{Lt.}}\begin{vmatrix} \frac{\partial^2\psi}{\partial x^2} & \frac{\partial^2\psi}{\partial x\partial y} \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial y}\end{vmatrix}, \qquad \underset{\psi\to 0}{\text{Lt.}}\begin{vmatrix} \frac{\partial^2\psi}{\partial x\partial y} & \frac{\partial^2\psi}{\partial y^2} \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial y}\end{vmatrix}$$

should be different from zero

(ii) $$\frac{\dfrac{\partial^2\psi}{\partial x^2}}{\dfrac{\partial^2\psi}{\partial x\partial y}} = \frac{\dfrac{\partial^2\psi}{\partial x\partial y}}{\dfrac{\partial^2\psi}{\partial y^2}} = \underset{\psi\to 0}{\text{Lt}}\ \frac{\dfrac{\partial g}{\partial x}}{\dfrac{\partial g}{\partial y}}$$

We shall write down the value of $\frac{dy}{dx}$ for the function $\psi\,(x, y)=0$.

$$\frac{dy}{dx} = \underset{\psi\to 0}{\text{Lt.}}\ \frac{\dfrac{\partial\psi}{\partial x}}{\dfrac{\partial\psi}{\partial y}} = \underset{h\to 0,\ k\to 0}{\text{Lt.}}\ \frac{\dfrac{\partial\psi\,(x+h,\ y+k)}{\partial x}}{\dfrac{\partial\psi\,(x+h,\ y+k)}{\partial y}}\,{}^{*}$$

$$= \underset{h\to 0;\ k\to 0}{\text{Lt.}}\ \frac{h\dfrac{\partial^2\psi}{\partial x^2} + k\dfrac{\partial^2\psi}{\partial x\partial y}}{h\dfrac{\partial^2\psi}{\partial x\partial y} + k\dfrac{\partial^2\psi}{\partial y^2}}$$

From Hill's theorem mentioned in the previous para, it follows that this limit is equal to either of the expressions

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* If (x_1, y_1) is the point at which $\frac{dy}{dx}$ is required, $\psi\to 0$ means that $x\to x_1$, $y\to y_1$. h and k are infinitesimals which tend to zero so that we have always $\psi\,(x_1+h,\ y_1+k)=0$.

$\dfrac{\frac{\partial^2\psi}{\partial x^2}}{\frac{\partial^2\psi}{\partial x\partial y}}$, $\dfrac{\frac{\partial^2\psi}{\partial x\partial y}}{\frac{\partial^2\psi}{\partial y^2}}$ The proof can now be completed on the same lines as Hardy's proof of Hill's theorem (*Vide* Hill's paper, *loc cit*). [The assumption will have to be made that $\psi(x, y)=0$ defines y as a function of x, in the case of Hill's theorem, this was true by the theorem on implicit functions The present theorem as well as Hill's theorem indicate in essence the principle of Jacobians, whatever subtleness may be adopted for the formal proofs.]

[*Note:* It might happen that $\frac{\partial^2\psi}{\partial x^2}$ and $\frac{\partial^2\psi}{\partial x\partial y}$ are both zero when $\psi=0$, but that $\frac{\partial^2\psi}{\partial y^2}$ is not zero, (or $\frac{\partial^2\psi}{\partial y^2} = \frac{\partial^2\psi}{\partial x\partial y} = 0$, but $\frac{\partial^2\psi}{\partial x^2} \neq 0$). It is therefore necessary to consider the limits of both the determinants in (1). If $\frac{\partial^2\psi}{\partial x^2}$, $\frac{\partial^2\psi}{\partial x\partial y}$, $\frac{\partial^2\psi}{\partial y^2}$ are all zero, the theorem breaks down, but the method of analysis is easily extended to such cases.]

Examples:

(7) To test whether $v=0$ is a singular solution of $(v+2)p=y(v+1)(\log v)^2$, where $v=\sqrt{1+y^2}-1$.

Here $\frac{\partial v}{\partial x}=0=\frac{\partial v}{\partial y}$ whenever $v=0$.

$\frac{\partial^2 v}{\partial y^2}=(1+y^2)^{-\frac{3}{2}}$ which is equal to 1, when $v=0$ The primitive is $c=x+\frac{1}{\log v}$

$$\therefore \underset{v\to 0}{\text{Lt.}} \begin{vmatrix} \frac{\partial^2 v}{\partial x\partial y} & \frac{\partial^2 v}{\partial y^2} \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial y} \end{vmatrix} = \underset{v\to 0}{\text{Lt.}} \begin{vmatrix} 0 & 1 \\ 1 & \frac{1}{v(\log v)^2}\cdot\frac{\partial v}{\partial y} \end{vmatrix}$$
$$= -1$$

$v=0$, *i.e.*, $y=0$ is however a solution evidently. It is thus a singular solution.

(8) The same problem for the equation

$(v+2)(xp-y) = xy(v+1)(\log v)^2$ where $v = \sqrt{1+\frac{y^2}{x^2}} - 1$

It is found that when $v=0$, $\frac{\partial v}{\partial x}$, $\frac{\partial v}{\partial y}$, $\frac{\partial^2 v}{\partial x^2}$, $\frac{\partial^2 v}{\partial x \partial y}$ are all zero, but $\frac{\partial^2 v}{\partial y^2} = 1$ g is given by $x + \frac{1}{\log v}$.

$$\underset{v \to 0}{\mathrm{Lt}} \begin{vmatrix} \frac{\partial^2 v}{\partial x \partial y} & \frac{\partial^2 v}{\partial y^2} \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial y} \end{vmatrix} = -1.$$

$v = 0$ is therefore a singular solution.

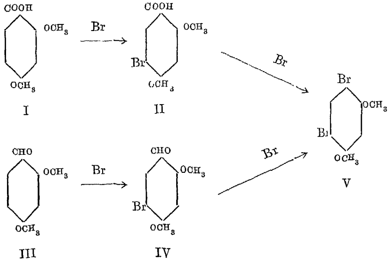
All the examples in this paper except (5) and (6) are taken from Hill's paper.

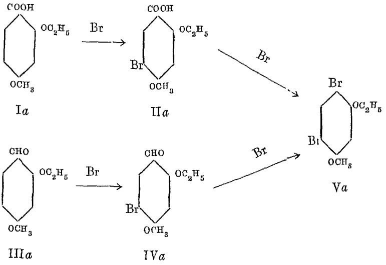
SUBSTITUTION IN RESORCINOL DERIVATIVES.

BROMO-DERIVATIVES OF RESORCINOL METHYL ETHYL ETHERS.

BY M SESHA IYENGAR AND H SUBBA JOIS

It has been shown that 2 · 4-dimethoxybenzaldehyde and 2-ethoxy-4-methoxybenzaldehyde and their corresponding acids yield on bromination monobromo-aldehydes and acids respectively, the bromine taking up the position 5 (M. G. Srinivasa Rao, C Srikantia and M. Sesha Iyengar *J Chem. Soc*, 1929, 1581). As a result of further study it is found that during the bromination of the above-mentioned aldehydes and acids, although the main products are monobromo-derivatives, yet a small quantity of dibromo-derivatives of resorcinol-ethers could be isolated, the second bromine atom replacing the aldehyde or the acid group. The monobromo-aldehydes and acids were also found to yield on further bromination identical dibromo-resorcinol ethers.





Experimental.

Bromination of 2 · 4-dimethoxy benzoic acid (I).—The acid (2 g.) was brominated by treating a solution of it in glacial acetic acid with bromine in molecular proportion (also dissolved in twice its volume of glacial acetic acid) and by frequently shaking in the cold. A colourless crystalline substance separated and the supernatant liquid remained pale yellow even after some hours. The precipitate was filtered off, washed first with acetic acid and then with water (yield 2 1 g.) On recrystallization from acetic acid the solid melted at 196-197° and was found to be 5-bromo-2 . 4-dimethoxybenzoic acid (*II*) (*loc cit*) The filtrate on dilution with water gave a white precipitate which on recrystallization from acetic acid melted at 140-141°. This bromo-derivative (yield 0 75 g) was insoluble in sodium bicarbonate and its melting point was not lowered when mixed with 4 · 6-dibromo-resorcinol dimethyl ether (M. Kohn and G Loff *Monatschefte, f Chemie.* 1925, **45**, 589-595). 5 Bromo-2 : 4-dimethoxy-benzoic acid (*II*) on further bromination in acetic acid solution yielded 4 · 6-dibromo-resorcinol-dimethyl-ether (*V*).

Bromination of 2 · 4-dimethoxy-benzaldehyde (III).—The aldehyde on bromination in the manner detailed above yielded a precipitate 5-bromo-2 . 4-dimethoxy benzaldehyde (*IV*) as the primary product and the filtrate on dilution with water gave a white precipitate as the secondary product This latter on recrystallization from acetic acid melted at 140-141°. It yielded neither an oxime nor a hydrazone and was found to be 4 : 6-dibromo-resorcinol-dimethyl-ether (*V*) The same product (*V*) was also got by further bromination of (*IV*).

4 : *6-dibromo-resorcinol-1-ethyl-3-methyl-ether* (*Va*) ·—2-ethoxy-4-methoxy-benzoic acid (2 g) was brominated in acetic acid solution with bromine in molecular proportion in the manner detailed above when a precipitate of the corresponding 5-bromo-derivative (*IIa*) m p. 193-194° (*loc. cit*) was got as the main product (yield 2.2 g), while the filtrate on dilution with water yielded a colourless crystalline substance (yield 0.8 g.) which on recrystallization from acetic acid melted at 98-99° This compound is found to be 4 : 6-dibromo-1-ethyl-3-methyl-ether (*Va*) It was insoluble in sodium bicarbonate (Found Br , 51.8 per cent , ($C_9H_{10}O_2Br_2$ requires 51.57 per cent).

An identical substance was got as the secondary product by brominating 2-ethoxy-4-methoxy-benzaldehyde (*IIIa*) in the manner detailed above along with 5-bromo-2-ethoxy-4-methoxy-benzaldehyde (*IVa*) as the primary product (*loc cit.*). The secondary product yielded neither an oxime nor a hydrazone. The same dibromo-compound was got by further bromination of (*IIa*) and (*IVa*) separately, thereby showing the possibility of the acid group in one and the aldehyde group in the other having been replaced by the second bromine atom.

The above dibromo-derivative was also found to be identical with the product obtained by brominating resorcinol-methyl-ethyl-ether with bromine while under similar conditions resorcinol-dimethyl-ether yields 4 . 6-dibromo-resorcinol-dimethyl-ether (Honig, Ber., 1878, **11**, 1041 , Tiemann, Parrisius Ber., 1880, **13**, 2365, M. Kohn and Loff *Monatschefte*, *loc. cit.*).

AUTOMATIC PULSATIONS IN PLANTS.

BY L NARAYANA RAO, M.Sc.
(Assistant Professor of Botany, Mysore University.)

The demonstration of automatic pulsation in plants deserves special interest from the fact that Sir J C Bose's researches have shown that it is the pulsating activity of a propulsive layer that maintains the ascent of sap

The problem of ascent of sap to the top of the trees sometimes as high as 150 metres, baffled inquiry for more than 200 years. According to the generally held physical theory, living cells take no part in the process , of the physical processes that have been invoked, neither capillarity nor atmospheric pressure can offer any explanation of the phenomenon. As regards the osmotic action, it is too slow a process to account for the relatively quick rate of the movement of sap.

The idea that any physiological activity could underlie the ascent of sap received a severe blow from the experiment of Strasburger on the action of poison ; he came to the conclusion that poisonous solutions did not produce any change in the rate of ascent of sap nor in the attitude of the leaves of the plant.

Sir J C. Bose has, however, shown that poisonous solutions cause an immediate retardation and final abolition of the ascent of sap. This is simultaneously indicated by the continuous diminution of the rate of suction and by the increasing fall of the indicating leaf * The activity underlying the propulsion of sap is not confined to any particular region but exists throughout the length of the plant. After the application of poison successive zones of the living stem are put out of action, resulting in a diminished rate of ascent and final abolition.

He has also shown that irrigation with cold water retards the rate of ascent of sap while application of warm water enhances it. Plasmolytic agents induce a temporary retardation or arrest, while application of fresh water revives it In contrast to this is the action of poisonous solutions which cause a permanent abolition of the ascent of sap.

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* *Motor Mechanism of Plants*, 1928, p 306

It has also been shown that physiological changes which enhance the pulsatory activity of the animal heart and that of the Desmodium leaflet also cause an enhancement of the activity of the ascent of sap , agents which depress the activity of these organs also depress or arrest the ascent of sap.

The results of these experimental investigations lead to the conclusion that the movement of sap is dependent upon physiological, and not physical action ; the source of the activity is to be sought in the living tissue of the stem or the petiole, the propulsion of sap being maintained by a pulsating mechanism similar to that in the cardiac tissue of the animal and in the pulsatory tissue of the Desmodium leaflet.

The characteristics of the pulsatory activity of Desmodium leaflet are therefore expected to cast a flood of light on the obscurities of the phenomenon of the ascent of sap. I, therefore, undertook to conduct a large number of experiments that have been carried out at the Bose Institute on the automatic pulsations of Desmodium.

The lateral leaflets of Desmodium execute pulsating movements, the characteristics of which are very similar to those of the rhythmic movement of the heart. The pulsatory movements of Desmodium are described as spontaneous ; but strictly speaking there is no such thing as spontaneous movement. The energy which expresses itself in pulsating activity is derived by the plant either directly from the external sources or from the excess of such energy already accumulated and held latent in the tissue. When the storage is exhausted by keeping the plant in a dark room, the so-called spontaneous movement comes to a stop ; in this state of standstill the pulsating activity becomes revived by fresh stimulation.

The isolated petiole containing the lateral leaflets is mounted water-tight in the shorter end of a narrow U-tube. The longer end of the tube is filled with water and exerts a certain amount of internal hydrostatic pressure which is favourable for the maintenance of uniform pulsation.

The arm of the recording lever is attached by means of a cocoon thread to a point about the middle of the leaflet by means of a drop of shellac varnish As the pull exerted by the minute leaflet is very feeble, the writer has to be made extremely light. It is desirable to obtain data for accurate time measurements of different phasic movements of the leaflet. This has been secured by the most perfect Oscillating Recorder in which the recording plate is made to execute a to and fro movement either once in a second or once in four seconds.

Experiment 1.—As an example of the extreme regularity that can be secured in the pulsating movement I reproduce the following record which was obtained during the period of 36 minutes The successive dots are of intervals of four seconds; as there are nine complete pulsations the period for one complete pulsation is four minutes. Under uniform conditions the pulsations remain constant Any change in the external conditions is followed by an appropriate change in the amplitude or period of the pulsation. When the temperature is moderately high as in summer the period of a single pulsation may be as short as two minutes, but in colder season the period may be as long as five minutes

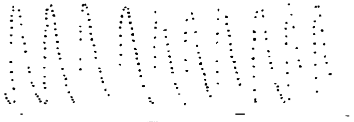

Fig. 1.

Uniform pulsations of Desmodium leaflet for 36 minutes Up-curve represents systolic contraction, down-curve diastolic expansion.

Time-Relations of the Pulsating Movement.

The "up" and "down" movement of the Desmodium leaflet has certain definite peculiarity. The "up" movement recorded by the "down" curve is executed somewhat slowly and comes to a pause for a certain length of time at the extreme "up"-limit There is in reality no absolute cessation of movement but at the turning point the "up" is reversed to "down" movements and *vice versa* After reaching the extreme up-position the down movement is commenced and this is accomplished in a much shorter time. After reaching the lower position there is a pause once more, when the cycle is again repeated

Experiment 2.—I give a detailed account of a single pulsation taken on a fast moving plate, the successive dots being at intervals of four seconds. The period of an entire pulsation was 164 seconds of which the down movement or systolic contraction was accomplished in 44 seconds followed by a short post-systolic pause lasting for 12 seconds The up movement

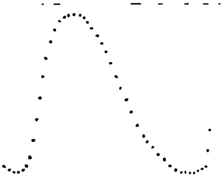

Fig. 2.

A single pulse of Desmodium leaflet taken on a fast moving plate. Note quick rate of systolic movement and post-systolic pause, slow rate of diastolic movement and long post-diastolic pause

or diastolic expansion extended over 80 seconds immediately followed by the post-diastolic pause of the duration of 28 seconds The facts to be noticed are that the systolic is much quicker than the diastolic movement and that the post-diastolic pause is more protracted than the post-systolic pause.

Internal Hydrostatic Pressure on Pulsation.

A certain amount of internal hydrostatic pressure is essential for the maintenance of pulsating activity. Thus the quiescent heart of a Snail can be made to pulsate by increasing the inter-cordiac pressure Similarly a condition of draught brings the pulsation of the Desmodium leaflet to a state of standstill, a revival being produced by irrigation The ascent of sap is likewise arrested under prolonged draught and revived after increased turgor produced by absorption of water.

Effect of Ether

Experiment 3.—The effect of a mild narcotic like ether is a depresser of pulsating activity, as seen in the reduction of the amplitude of pulsation (Text Fig. 3). A prolonged application would have arrested the pulsation. Air was, however,

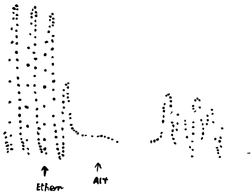

Fig. 3.

Effect of Ether vapour on the pulsations. Note the arrest of pulsations under the mild anæsthetic applied at the first arrow and subsequent revival on substitution of fresh air at the second arrow.

substituted for the ether vapour in the chamber containing the plant. The result is seen in the slow revival of activity.

Effect of Chloroform.

Experiment 4.—In contrast with the effect of ether is the toxic action of the strong narcotic chloroform The first two pulsations are normal, chloroform vapour being introduced into the plant-chamber at the point marked with the arrow.

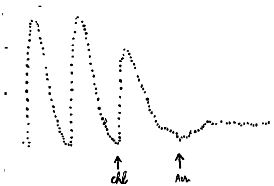

Fig. 4.

Action of Chloroform. Permanent arrest of pulsation which could not be revived by the admission of fresh air, This caused a complete arrest of the pulsation and the death of the leaflet; for substitution of fresh air at the second arrow was quite ineffective, since there was no revival of the pulsation.

Effect of KNO_3 and KCN Solutions.

Plasmolytic solution of KNO_3 arrests the ascent of sap. Poisonous solution of KCN also arrests the ascent of sap. The difference in the two cases is in their after-effects. The arrest of ascent by KNO_3 solution is temporary, application of fresh water revives the ascent of sap. KCN solution, on the other hand, induces a permanent abolition of the ascent of sap which cannot be revived by application of fresh water.

Experiment 5.—This difference is well illustrated by experiments carried out with the leaflet of Desmodium. The first two pulsations are uniform and normal. KNO_3 solution was then applied at the first arrow. This caused an arrest of pulsation in the course of 10 minutes. The arrest was, however, not permanent, since application of fresh water at the second arrow caused a revival of pulsatory activity in the course of 27 minutes. In sharp contrast with this is the effect of the poisonous KCN solution which caused a permanent abolition of pulsation; application of fresh water being unable to revive it.

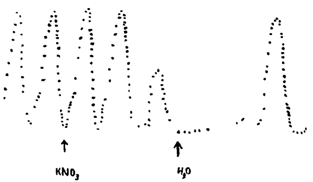

Fig. 5.

Effect of application of plasmolytic solution of KNO_3 at the first arrow. Application of fresh water at the second arrow caused subsequent revival of pulsations

Effect of Variation of Temperature.

Experiment 6 —After taking records of two normal pulsations, water at 5°C. was applied at the cut end of the petiole. This caused an arrest after two more pulsations. Water at 36°C. was next substituted for the ice-cold water. This resulted in the revival of pulsatory activity.

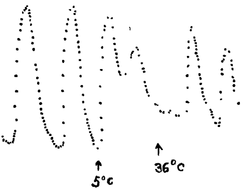

Fig. 6.

Effect of temperature on the pulsatory activity of Desmodium. Application of water at 5°C. caused an arrest. Pulsations revived by application of water at 36°C.

It is thus seen that the pulsations could be inhibited or activated by alternately lowering or raising the temperature below or above certain thermometric minimum. The ascent of sap is likewise found to become arrested or revived by variation of temperature below or above a minimum temperature.

Some of the important results established by investigations on the automatic pulsations of Desmodium leaflet is that the activity is permanently abolished by the action of poisonous solutions. Temporary arrest followed by revival are also produced by the alternate fall and rise of temperature

The very definite results exhibiting the characteristics of pulsatory activity give clear indications of the mechanism of the ascent of sap The permanent abolition of ascent of sap by the action of poison proves that the phenomenon is essentially due to the activity of living cells The alternate arrest and renewal of the ascent of sap under temperature variation below and above the critical point, parallel to those in Desmodium leaflet, prove that a living pumping mechanism is essential in the propulsion of sap.

THE UNIVERSAL STAGE AND ITS USES.

PART I.

BY CHARLES S. PICHAMUTHU
(*Assistant Professor of Geology, Central College*)

Introduction.

During the last academic year, the Department of Geology, Central College, added a Universal Stage to its collection of microscope accessories. This is an ingeniously devised instrument with four axes of rotation, whereby with a single mineral section one could study such crystallographic properties as the planes and axes of the indicatrix, the optic axes, the planes of cleavage, twin planes and also sometimes the crystal faces It is rather strange that the universal stage methods have not found much favour with the English and American scientists and this explains the fact that practically no literature on this subject exists in English, all the available literature being either in French or German

Development of Rotation Instruments.

One of the first rotation apparatus used with a microscope was that invented by H. B. Leeson (1) in 1848 It had three movements, two of them horizontal and one vertical, whereby a crystal could be turned to any position in two planes

The next advance was made by S Highley (2) Instead of the ordinary revolving stage, this instrument carried two concentric graduated rings, one of which had the usual movement in azimuth, while the other was pivoted and had a movement in altitude. The advantage of using spherical segments was first pointed out by Adams (3) in 1875.

In 1889, E. v Fedorow first announced in a meeting of the Imperial Society of Mineralogy of St Petersburg, a universal stage which was very useful for goniometric work. Two years later he suggested the construction of a universal stage on the same principle but designed for optical studies of crystallized minerals In 1893 he published his classical work describing the uses of the universal stage in mineralogy and petrography (4, 5) The stage then had only two axes of rotation, In

1896 he published a few papers on the application of the universal stage methods in the study of felspars (12, 14, 15) in which he gave details of working with a stage with three axes of rotation. Some time after, in a series of papers (19-21, 23, 26-29), he described the various modifications both in the apparatus as well as in his methods. In the improvement of the stage Fedorow was associated with Leiss (8, 9, 16, 18) and Klein (10, 17) who jointly made in the workshop of Fuess the type of instrument such as is used at the present time.

Fedorow's Universal Stage.

The whole instrument is carried by a broad stage plate with a wide central aperture which can be clamped to the stage of the microscope by means of two screws From this stage plate rise vertical brackets on which is supported the main horizontal axis A large milled head operates the graduated vertical circle round this axis A screw at the opposite end serves to fix this circle in any position The outer horizontal circle of the stage can be moved by means of its milled periphery. Within this in gimbal manner a second ring is fixed which could be inclined to the right or to the left and the angle of inclination read on a small semicircular vernier. In many of the instruments this inclination is read on two graduated arcs placed to the right and left These are known as Wright's arcs after the name of the person who first suggested their use Within this inner circle and in its plane, there is a glass disc which can be rotated. This bears two cross-wires and this disc is capable of being slightly raised or lowered by means of a screw arrangement On this the mineral to be examined is placed and over this is clamped by means of two screws, a metal holder containing a glass segment of known refractive index A similar segment but of a bigger diameter is fitted beneath the glass plate In size the segments are as much less than perfect hemispheres as the thickness of the glass disc and the microslide, so that when they are in position their outer contours form a perfect sphere the centre of which is found in the plane of the mineral section.

To avoid total reflection during great inclinations, it is necessary to place between the two segments a medium with refractive index higher than air, *e.g*, glycerine or cedar wood oil. The refractive index of water-free glycerine is about 1 469 and this when used with segments of refractive index 1 70 first brings in total reflection during inclinations of about

60°. Since measurements made under inclinations greater than about 50° are not quite accurate, glycerine will suit all conditions Cedar wood oil when used with segments of refractive index 1.70 brings in total reflection only by a little higher inclination, *i.e.*, for about 63°. Therefore it is of no practical use to employ immersion fluids of still higher refractive index.

The observation direction in the mineral coincides with the geometrical position only when the mineral and the segments have similar refractive indices.

Axes of Rotation.

An inspection of the instrument will show that there are four axes of rotation. These are in two pairs at right angles to each other and are capable of movement in space. A fifth axis which coincides with the observation direction is always fixed in space. All these five axes should intersect at a point which must lie in the plane of the section.

The arrangement of the five axes are as follows :—(Text Fig. 1) ; the axes A_1 and A_2 form the first pair which are at right angles to each other The graduated circle belonging to A_1 is the smallest In the plane of this circle lies the axis A_2. By movement round it, the position in space of A_1 is changed.

A_3 and A_4 form the other pair which are also at right angles to each other. These belong to the outer circle of the universal stage. By movement round A_3, the positions in space of A_1 and A_2 are changed. In the plane of the circle which

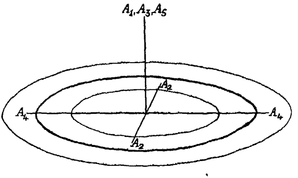

Fig. 1.
(after M. Berek)

belongs to A_3 lies the axis A_4. By movement round it, the positions in space of A_1, A_2 and A_3 are changed.

A_5 is fixed in space and coincides with the observation direction. To it belongs the graduated circle of the stage of the microscope. Movement round this axis changes the position in space of the axes A_1 to A_4.

If these indices are followed, it will be seen that movement round any axis will shift the positions of all the other axes which have a lower index Also, if A_1 and A_3 are placed parallel to A_5, then all the axes with indices of uneven numbers are vertical and those with even numbers are horizontal. To A_1 belongs the innermost and to A_5 the outermost circle. A_1 is always the direction of the normal to the section, and A_5 the direction of the axis of the microscope

The above notation for the axes has been suggested by M Berek. Since the notation usually found in books on the subject is that adopted by Fedorow and Nikitin, it may be useful to give here their corresponding equivalents. The axis A_1 is designated by N, A_2 by H, A_3 by M, A_4 by J and A_5 by A. According to this notation, in the fundamental position of the universal stage, H and J are the horizontal axes and N, M and A, the vertical axes ; A is the fixed axis of the microscope tube and N the normal to the section

Setting up and Centering.

The setting up of the instrument and correct centering play a very important part in all universal stage measurements, and if not heeded to errors are liable to be introduced in all subsequent work

It is always better and especially so when the positions of extinction have got to be accurately measured, to use artificial illumination rather than diffused daylight. For very accurate work, a filter may be used which allows only the orange and red rays to pass through, for in this portion of the spectrum there is very little dispersion

Parallel light is used for almost all observations and this makes it possible to work with lower power objectives and to cover a larger field.

The microscope is first centred in the usual way. Then the universal stage is placed on the stage of the microscope after removing the central detachable disc. This is done in order to enable the universal stage to be rotated right round on the A_4 axis. The universal stage is placed in such a position that the milled head operating the A_4 axis is to the right of the observer Before fixing the stage firmly, advantage is taken of the slight play in the screw slots, to make the intersection point of the cross-wires of the ocular to coincide with the intersection point of the cross-wires of the innermost circle of the universal stage.

The intersection point of the cross-wires of the universal stage is the point through which all the axes of rotation pass, and so when the circles are rotated round A_1 or A_3 axis, the intersection of the cross-wires of the ocular should coincide with that of the intersection of the cross-wires of the universal stage. This will not exactly be the case when the stage is inclined round A_2 or A_4 axis, because these axes usually pass a little above the glass disc so as to be in the plane of the mineral section.

Next, see whether the axis A_4 coincides with the E-W cross-wire and the axis A_2 with the N-S cross-wire of the ocular, and determine the fundamental positions of the axes A_2 and A_1 The procedure as given by W. Nikitin (38) or L Duparc (41) may be followed.

To determine the true zero position of the axis A_5 M Berek (42) has suggested the following method ·—Place the pointers of the circles A_2 at zero, A_3 at 90° and A_4 at zero Raise the tube of the microscope by means of the coarse adjustment so that a dust particle on the surface of the upper segment is focussed. In order to see the dust particles better, it is advantageous to displace the mirror and get a dark field illumination. The dust particles then appear bright in a dark background. Now incline round A_4 and observe the movement of a dust particle in the neighbourhood of the vertical cross-wire. By a small inclination round A_2 a particle could be placed directly on the cross-wire and then the course of its movement in relation to the cross-wire can be better judged. Turn round A_5 till the movement of the particle by inclining the stage round A_4, is strictly parallel to the vertical cross-wire. Thus the initial position of A_5 can be found correct to 0·1°.

The Principle Underlying the Universal Stage Methods.

In order to make any direction *m* in a section to coincide with the direction of observation o, movement round the two axes A_1 and A_2 are enough. The section is first rotated

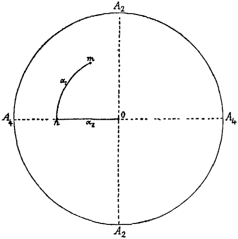

Fig. 2.

through an angle α_1°, round the axis A_1 (Text Fig. 2), till m reaches the point n on the equator, and then by an inclination of α_2° round the axis A_2, n will lie exactly in the direction of observation o

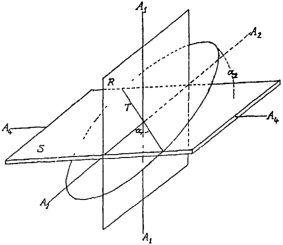

Fig. 3.

(*After Duparc and Reinhard*)

A similar procedure will also bring a plane of the ellipsoid to coincide with any plane of reference In Fig. 3, let S be a mineral section on which the line T represents the trace of one of the planes of the ellipsoid. To make this plane of the ellipsoid coincide with the plane of reference R only two operations are necessary First of all a rotation of an angle α_1° in the horizontal plane round the axis A_1 when the trace T will lie in the plane of reference R; secondly, by inclining to the right or to the left, as the case may be, through an angle a_2^0 round the axis A_2, the plane of the ellipsoid will coincide with the plane of reference. If the reference plane is parallel to the principal section of one of the nicols, then the mineral will be extinguished In such a position if the section is rotated round the axis A_4, which is perpendicular to the plane of reference and oriented E-W, there will be extinction in all the positions because A_4 will then be one of the axes of the ellipsoid. In the same way, it is possible to determine the co-ordinates of a cleavage plane or of a crystal face.

Stereographic Nets.

The co-ordinates thus obtained have got to be represented on a stereographic projection. For this purpose the Fedorow's stereographic net may be used This contains two superposed systems analogous to the geographical network; a first system composed of a series of meridian and parallel circles at intervals of 5°, projected on the equatorial plane, the meridian planes being represented by diameters of the primitive circle, and the parallels by a series of concentric small circles surrounding the centre of the projection; and a second system formed by similar planes constructed in relation to one of the meridians taken as the axis of the co-ordinates; the arcs of projection of the meridian planes are borne on the extremities of this axis which is one of the diameters of the fundamental circle. The parallels form a series of arcs of circles of different curvatures which have their concavity away from the extremities of this axis, on which are situated their centres (generally outside the primitive circle). The plane of the equator is projected as a diameter of the primitive circle perpendicular to the axis of projection. There are two such meridian projections, whose axes are perpendicular and in addition a third projection on the plane of the equator.

The primitive circle is graduated both in a clockwise and anti-clockwise direction, the one or the other being used according as whether the plotting is made on a tracing paper with the projection plat as base, or whether it is made directly on the net.

At present the most commonly used stereographic net is that devised by Wulff (25). This net gives the projections of great circles and of vertical small circles 2° apart. When the net is of the normal diameter of 20 cm. readings correct to ½° can be made. To prevent crumpling it is best to paste the net on a thick board. Over this a tracing paper may be laid Mark on the tracing paper the centre of the circle and a few arcs of the primitive circle so that the paper may be kept in place without shifting during the whole course of plotting. Indicate the zero of the primitive by a mark.

The initial position of the zero for rotations round A_1 is placed as a rule to the south pole of the net. Beginning with this zero the graduations of the primitive circle proceed in a clockwise direction

For a proper representation of the results obtained, it is essential to note carefully the directions of rotation round the axes A_1, A_3 and A_5. A_1 may be rotated both in the clockwise or anti-clockwise direction, but A_3 and A_5 are always rotated only in the anti-clockwise direction.

The plane of the mineral section is always taken as the plane of the stereographic projection.

Distinction between Isotropic and Anisotropic Minerals.

By a proper inclination of the mirror of the microscope illuminate the mineral as brightly as possible. Incline the stage around the axis A_4 up to about 60° and see if the illumination persists. This precaution is necessary to avoid errors arising out of the presence of air bubbles, which due to total internal reflections, cause darkness during inclinations.

If this does not happen, cross the nicols and rotate the stage around A_5 for more than 90° in any direction. One of two things might then happen :

(1) The field may be lighted and darkened alternately at intervals of 90°. The mineral is then anisotropic.

(2) The field may become dark and remain so during a complete rotation round A_5. In this case, incline around A_4 about 45° in any direction and rotate the stage around A_5 Two cases are possible :

(*a*) The field may be lighted and darkened alternately. The mineral is anisotropic. The plane of the mineral section is then perpendicular to an optic axis

(*b*) If the field remains dark throughout, incline A_4 about 45° in the direction opposite to that in the previous case, and rotate the stage over a big angle around A_5. One of two cases may arise :

(i) If the field is lighted and darkened alternately the mineral is anisotropic and biaxial. The original mineral section as well as the plane of the mineral in (*b*) are perpendicular to the optic axes.

(ii) If the field remains dark throughout, the mineral is isotropic.

Distinction between Uniaxial and Biaxial Minerals.

Place the stage in its fundamental position and turn round A_1 till the mineral is extinguished Then incline up to 60° round A_4 in either direction and see if the darkness persists or is destroyed

With A_4 again in its zero position, turn around A_1 till the second position of extinction is obtained. Incline around A_4 as in the preceding case and observe if the extinction is preserved or destroyed Three cases are possible·

(1) Neither of the two extinctions may persist during rotation round A_4. The mineral is then biaxial.

(2) One of the two extinctions may persist and the other destroyed In this case, examine first the extinction which persists as follows: Rotate the stage 45° around A_5 in one or in the other direction from its original position The section will then be brightly lighted Unclamp A_4 and incline between 60° to 68° round this axis in each direction and notice the change in the interference colours. Three alternatives are possible·—

(*a*) The section may remain bright in all the positions. There is neither extinction in certain positions nor a marked lowering of the polarization tints during great inclinations. The mineral is then biaxial and the axis which coincides with A_4, is X or Z but never Y.

(*b*) During the inclination, two positions of extinction separated by a lighted interval may be noticed. The mineral is then biaxial and the axis which coincides with A_4 is Y.

(*c*) During the inclination one position of extinction may be noticed or at least a lowering of the interference colours up to grey for great inclinations. By a rotation round A_3, place the axis A_2 in its fundamental position; similarly place A_4 also in its fundamental position Clamp A_3, and by a rotation round A_1 bring the section to its extinction position. Then incline about 40° to 50° round A_2 in one or the other direction. By a rotation round A_3 bring the section successively into the two positions of extinction. By inclining round A_4 notice for which of the two positions of extinction the darkness persists or is destroyed The alternatives are as follows:

(i) Neither of the two extinctions may persist The mineral is then biaxial.

(ii) One of the two extinctions may persist. The mineral is then uniaxial.

(3) Both the extinctions persist By rotation round A_3, place the axis A_2 at 45° to A_4. Clamp A_3 and bring the mineral to the extinction position by rotating round A_1. Incline A_2 about 40° to 50° and after clamping it in this position, rotate round A_3 till the mineral is extinguished, and notice whether the extinction is preserved or destroyed during the inclination of A_4 in both directions. Two cases arise :—

(*a*) Neither of the two extinctions persists. The mineral is biaxial.

(*b*) One of the extinctions persists. The mineral is uniaxial.

If the section is isotropic, that is, if it remains uniformly extinguished between crossed nicols during a complete rotation round A_5, then place A_4 in its fundamental position and incline around A_2 in both directions up to 50°, and observe whether the darkness is maintained or destroyed Two cases are possible.

(1) The darkness may be destroyed. The mineral is then biaxial

(2) The darkness may be maintained or the mineral very slightly illuminated. Turn the section round A_1 about 45° to 90° from its position in the first observation, then incline steeply round A_4. One of two things may happen:

(*a*) The darkness may be destroyed. The mineral is then biaxial.

(*b*) The darkness may be maintained or very slightly destroyed. The mineral is then uniaxial

Determination of the Optic Axial Angle.

(i) The first method suggested was by Fedorow (5, 12). A summary of this procedure is given by Johannsen (37) In this method the apparent emergence of an optic axis is located and the angle which this makes to the normal to the section is found. The true optic axial angle is then calculated from the formula,

$$n \sin V = \sin E$$

where n is the mean refractive index of the mineral, V the true angle and E the apparent angle which this axis makes in air with the normal.

(ii) Another method was given first by Klein (11) in 1895 and later by Evans (30). This procedure is to be used for the determination of the optic axial angle in mineral sections immersed in a fluid having a refractive index as nearly as possible equal to that of β of the mineral.

(iii) The method of determining the position of the optic axes by means of the "optical curves" was also suggested by Fedorow (12) This method is based on the Biot-Fresnel law (37, pp. 406-411). A good summary of this procedure is given by Tutton (40) The intersection point of the extinction curves is the emergence of the optic axis. But these curves due to various sources of errors, do not ordinarily intersect in a point but form a polygon, the centre of which is taken as the true point of emergence Modifications of this method are given by Wright (24, 25). This method can be used only when both optic axes appear within the field of vision.

(iv) The following procedure may be followed for the direct determination of the optic axial angle All the circles are placed in their initial positions. A_3 and A_5 are clamped. The section is rotated round A_1 until the mineral is extinguished. Then, if the stage is inclined round A_4, the extinction will not always persist. Incline round A_4 until the section is at its brightest and then incline round A_2 in one or the other direction until the extinction position is reached. Then bring A_4 back to the original position and if then the mineral is not completely extinguished, it can be corrected by a small rotation round A_1. Incline again round A_4 and get the maximum extinction by inclining round A_2. Repeat this until finally a position is reached when for all inclinations round A_4 the extinction persists.

Determine first the plane of the ellipsoid which has the smaller inclination towards the normal to the section, in order to do this try the characters of both the extinction positions and start from that which has the smaller inclination to the normal to the section.

In order to determine accurately the position of a plane of the ellipsoid, it is very necessary to work with a small aperture Sometimes even this is not enough and a condenser will have to be used.

After determining the position of the plane, find out the character of the axis of the ellipsoid which is normal to this plane This axis now lies parallel to A_4. To determine its character rotate A_5 about 45° from its initial position so that A_4 comes to the diagonal position. Then incline round A_4 in both directions and observe whether the section is extinguished in any position. In this case also work with a small aperture The section will be extinguished when an optic axis passes through the field of vision. If this happens, that plane of the ellipsoid is the optic axial plane and the axis perpendicular to it is the optic normal Y. If the optic axes do not appear, the optic axial plane may sometimes be distinguished by its interference colours appearing brighter on one or both sides during great inclinations round A_4. If none of these signs appear, the character of the axis is to be determined by using the gypsum plate or the quartz wedge. During this operation the pointer of A_4 must be placed at zero.

The required data for the plane of the ellipsoid are the following :—

(i) The angle a_1° on the graduated circle belonging to the axis A_1.

(ii) The angle a_2° indicating the inclination of the circle belonging to the axis A_2. It is necessary to note whether the circle is inclined to the right or to the left, to signify this the letters *r* or *l* may be placed after the readings.

(iii) The character of the axis of the ellipsoid which lies parallel to A_4

(iv) The angle a_4° on the circle belonging to the axis A_4, at which an optic axis lies in the direction of observation.

On all graduated circles it is enough to take readings correct to half a degree. If a_2° is greater than $35\frac{1}{2}°$, then it is certain that the plane with the smaller inclination to the normal to the section has not been found

The degree of accuracy in determining the various data varies much. With a little care errors ought not to arise in the determination of the character of the axes of the ellipsoid, but the data for the co-ordinates of the planes of the ellipsoid are usually beset with errors of varying degree. The errors in the determination of the co-ordinates α_2° are as a rule greater than those connected with the co-ordinates α_1°. The results also are less accurate in proportion to the retardation being smaller. It is therefore advantageous in cases of weak birefringence to use thick sections whenever possible The data are also somewhat inaccurate when the inclination of the plane to the normal to the section is great Finally the co-ordinates of a plane which contains no optic axes ordinarily possess a higher degree of accuracy than the co-ordinates of the optic axial plane.

It is necessary to take a series of measurements and by getting the average of these readings, the co-ordinates are a little more reliable. But it must be recognized that an average value need not necessarily be quite an accurate estimate of the co-ordinates.

Plotting the Co-ordinates.—Place the zero of the tracing paper at α_1° of the primitive circle of the Wulff's net (Text Fig 4) and then count from the centre of the projection along the equator α_2°, to the left if the second co-ordinate is $\alpha_2^\circ l$ and to the right if it is $\alpha_2^\circ r$. Through that point and connecting the N and S poles, draw a meridian circle This represents the plane of the ellipsoid 90° from this plane and on the equator, mark the pole of this plane. This represents the axis normal to the plane.

If in the optic axial plane, one or both optic axes are found, then mark also the co-ordinates α_4° along the meridian circle which represents the plane. Take the intersection point with the equator as zero for plotting below the equator and as 360° for plotting above the equator

Correction for Refraction.—If the difference in the refractive index between mineral and segment is great, then all co-ordinates obtained by inclinations, *i.e.*, the co-ordinates α_2° and α_4° will have to be suitably corrected If the difference is not great, *e g.*, if segments of refractive index of 1·54 or 1·55 are used in the identification of the felspars, no correction for refraction need be made. Charts have been prepared to facilitate making these corrections. One such, after Fedorow, is given by Johannsen who has also described the method of using it. A very good chart is appended to Berek's

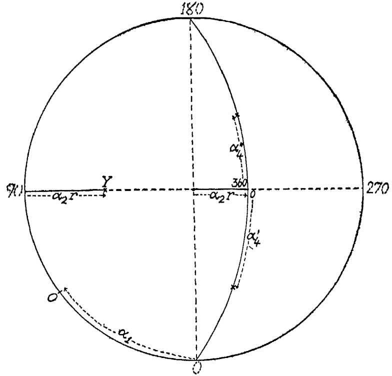

Fig. 4.

"Mikroskopische Mineralbestimmung mit Hilfe der Universaldrehtischmethoden".

Determination of a Second Plane of the Ellipsoid.—Place the various circles of the stage again in their original positions and determine the co-ordinates of the second plane in the same way as was done for the first plane. Find the character of the axis which is at right angles to this plane. All the determined data must then be entered on the stereographic projection. To do this turn the tracing paper on the Wulff's net so that the first plane has its intersection points on the primitive disposed E and W. The plane can thus be placed either above or below the equator. The second plane must always pass through the previously determined axis of the ellipsoid and must also be at right angles to the first plane. The intersection point of both the determined planes gives the position of the third axis of the ellipsoid.

The third plane is as a rule inclined very much from the normal to the section and so its direct determination with the universal stage is of no value because of the magnitude of the errors of measurement

Use of the Data—If both the optic axes are not found in the plane of the optic axes, then the axis which is situated at the intersection of the plane of the ellipsoid is the obtuse bisectrix. The optical sign of the mineral may be determined.

If at least one optic axis is present, then the angle which this makes with the nearest axis of the ellipsoid is half the optic axial angle Therefore in such cases 2V and the optical sign can both be found.

If both the optic axes are present, then the value of 2V is directly obtained The optical sign is easily determined.

The mineral is uniaxial if in the stereographic projection one of the determined optic axes coincides with an axis of the ellipsoid.

Examples.

The following examples illustrate the procedure to be followed for the determination of the planes of the ellipsoid as well as for the calculation of the true optic axial angle. By finding the character of the axis parallel to the A_4 axis, the optical sign of the mineral can in each case be known. The readings are entered in the tabular form suggested by M Berek

1. *Plagioclase*—Segments of refractive index 1·554 were used and so no correction for refraction is necessary.

No.	I Plane			II Plane						
	a_1	a_2	$\|A_4$	a_1	a_2	$\|A_4$	a_4'		a_4''	
	°	°		°	°		°	′	°	′
1	126	7 *l*	X	218½	19 *l*	Y	32	40	313	30
2	126½	8½*l*		216	21½*l*		33	15	313	25
3	127½	6½*l*		218	18½*l*		31	20	312	25
4	126½	6 *l*		216½	18 *l*		32	30	314	0
5	128	7½*l*		218	19½*l*		32	40	312	55
6	127½	7 *l*		216½	16½*l*		33	0	313	25
7	128½	6½*l*		215½	14 *l*		31	35	311	30
8	127	7½*l*		217½	18 *l*		32	40	313	10
9	128	8 *l*		218	18 *l*		32	0	312	20
10	127½	6 *l*		217	19½*l*		31	30	313	0
Mean	127¼	7 *l*		217	18¼*l*		32	19	312	58

The two axes of the ellipsoid are found to be X and Y. Therefore, the third axis which is in this case the acute bisectrix is Z. The optical sign of the mineral is thus positive. The angle between α_4' and α_4'' is the true optic axial angle.

$$2V = 32°19' + (360°0' - 312°58')$$
$$= 79°21'$$

This angle corresponds to a Labradorite of composition $Ab_{53}\ An_{47}$

The following stereographic projection embodies all the data obtained:

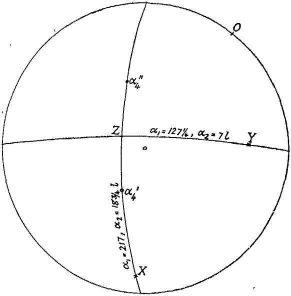
O
α_4''
Z
$\alpha_1 = 127\frac{1}{4}$, $\alpha_2 = 7l$
Y
α_4'
$\alpha_1 = 217$, $\alpha_2 = 183\frac{3}{4}$ l
X

Fig. 5.

2. *Aragonite.*—Segments of refractive index 1·649 were used.

No.	I Plane			II Plane				
	a_1	a_2	$\|\|A_4$	a_1	a_2	$\|\|A_4$	a_4'	a_4''
	°	°		°	°		° ′	° ′
1	119	1 *l*	Z	208½	4 *r*	Y	9 0	349 40
2	119½	½*l*		210½	5½*r*		8 30	350 0
3	118½	3 *l*		209½	5½*r*		8 40	350 30
4	118	1½*l*		209	5 *r*		8 55	349 45
5	120	1½*l*		210	6½*r*		9 5	350 40
6	118½	1 *l*		209	5 *r*		8 50	350 5
7	119	½*l*		209½	7 *r*		8 50	349 55
8	120	2½*l*		209	6½*r*		9 10	350 45
9	119½	1½*l*		208½	6 *r*		8 40	350 40
10	118	2 *l*		209½	5 *r*		9 0	350 10
Mean	119	1½*l*		209¼	5½*r*		8 52	350 13

The acute bisectrix in this case is X and therefore the mineral is negative.

$$2V = 8°52' + (360°0' - 350°13')$$
$$= 18°39'$$

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TIME AND ETERNITY.

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Thanks to Bergson and Einstein, Time has become the central problem of philosophy. Innumerable discussions are taking place all the world over, and day by day fresh aspects of the problem are being worked out—biological, psychological, and physico-mathematical The old antinomies of Zeno and Kant are given a fresh lease. The philosophical consequences of the principle of relativity are being drawn from all possible points of view. The richness and variety of contemporary thought is bound some day to lead to a new synthesis, more comprehensive than any earlier world-view. But it is clear that at the present time it is difficult to see the wood for the trees. If Bergson is the philosopher of evolution, we are waiting for a metaphysician to gather up the results of recent physical discoveries and present a picture of reality, indicating the true place of time therein.

The central problem is presented by the antithesis of Time as felt and Time as thought Perceptual time is agreed to be a continuous whole, whereas conceptual time is more or less agreed to be mathematical, discrete and infinitely divisible in character. Time as perceived has a felt duration, a continuous becoming, not a mere succession of discrete moments "If I raise my hand from A to B, this movement appears to me under two aspects at once. Felt from within, it is a simple indivisible act; perceived from without, it is the course of a certain curve, AB. In this curve I can distinguish as many positions as I please, and the line itself might be defined as a certain mutual co-ordination of these positions." (Bergson, *Creative Evolution*, p 96, 1914.) We cannot give up either view. Mathematical logic cannot convince us that our perception of change is discrete, that our felt duration is an illusion engendered by quick succession of momentary states. For, experience of succession cannot be derived from pure succession. Nor can we think of external reality as infinitely divisible, as a series of events succeeding each other, with no continuous ground underlying it. The 'ground' need not be the mysterious 'substance' of matter, which has done so much of mischief in science and philosophy from Descartes to the present day Confronted by this problem, philosophy has so far taken the usual methods of suppressing one or other of these two aspects of the problem In Idealism, the importance of time was not sufficiently stressed, as it was regarded as appearance, a form of manifestation. And no serious attempt was made to work out the view in all its detail, and render it intelligible So it convinced only the converted In the eyes of its critics, this doctrine of appearance was identified with illusion, pure and simple Hence the exhortation to take Time seriously The first to take Time seriously was Bergson He dismissed conceptual time as empty, spurious and 'spatial', and upheld perceptual time as the only concrete reality. Time becomes the very stuff of reality It is identified with change and duration Reality is change. There is nothing static. Everything is a flow The Universe is a creative evolution. Infinite divisibility and discreteness is dismissed as an illusion manufactured by the intellect, moulded in close contact with the least dynamic aspect of nature, namely, materiality. The puzzles of Zeno are solved But the logical atomist, the protagonist of conceptual time, is not satisfied B Russell has a great suspicion of this easy solution. For him, analysis is the road to reality, and the world can be analysed into a number of series of discrete moments The mind is a succession of sensations and images, and the world a succession of appearances

Thus present-day discussions of Time display opposite abstractions. One school of thought stresses duration to the exclusion of all distinctness, of all complexity. Change is regarded as one and indivisible, with no distinguishable parts or aspects. This view is represented by Bergson, who is the modern Heraclitus. Another school of thought stresses the succession of states, and regards time as consisting of an infinite number of static and momentary existences. This view sees nothing contradictory in regarding change as consisting of changeless units, particularly reinforced by George Cantor's mathematical theory of infinity. It is represented by Bertrand Russell, who is the modern Democritus. Both these opposing views are the result of abstract and one-sided interpretation of the facts of experience. Bergson takes his stand on the perceptual and immediate experience of time, emphasizes the indivisibility and ultimate primacy of 'duration'. Russell takes his stand on the succession of states revealed by analysis in our experience of change. The report of immediacy is final for Bergson, whereas analysis is the path-way to reality for Russell As usual, extremes meet, and both views commit the same fallacy—that of denying unity. Bergson seems disinclined to admit a unitary ground or essence, revealing itself in duration and speaks of 'pure duration' And Russell is equally emphatic in denying continuity of essence between the succeeding states He reduces perceptual continuity to mere appearance due to physiological and psychological conditions As usual, the truth consists in the synthesis of opposites. Reality is both duration and succession. If we interpret time as the aspect of succession we have to supplement it with the aspect of enduring ground or essence, to render it adequate to reality in its fulness This aspect is that of eternity Reality displays both the aspects of time and eternity. This view renders Bergson's duration concrete as the creative self-expression of reality. It renders Russell's atomicity intelligible as referring to the successive phases of its growth

TIME AS DISCRETE.

Bertrand Russell develops his view of time in Our Knowledge of the External World He outlines a special method of 'construction' by means of which he bridges the gulf between the world of common sense and the world of physics, between the world of things in continuous space and time and the world of electrons in mathematical space and time Applying Cantor's theory of infinity to time, he tells us that it is a *possible* and *necessary* construction from sense-data. From the continuity of sense-data, we are led by analysis inevitably to a compact series of an infinite number of timeless units. (He refers to this problem in the Analysis of Matter, but only to reiterate the views of Our Knowledge of the External World) Regarding the usual arguments for unity and indivisibility of change based on perceptual experience, his answer takes three forms :—

1. Physiological.
2 Psychological
3. Logical.

The physiological and psychological considerations are urged by Russell to prove that continuity of experience need not imply continuity of the objects of experiences, nor even continuity of sense-data. Snapshots may produce the illusion of change. The logical consideration is intended to prove that it is necessary to distinguish instantaneous states of objects and to regard them as forming a 'compact series'.

1. Physiological Proof of Discreteness.

"When any nerve is stimulated, so as to cause a sensation, the sensation does not cease instantaneously with the cessation of the stimulus, but dies away in a short finite time. A flash of lightning, brief as it is to our sight, is briefer still as a physical phenomenon: we continue to see it for a few moments after the light waves have ceased to strike the eye. Thus in the case of a physical motion, if it is sufficiently swift, we shall actually at one instant see the moving body throughout a finite portion of its course, and not only at the exact spot where it is at that instant. Sensations, however, as they die away grow gradually fainter; thus the sensation due to a stimulus, which is recently past, is not exactly like the sensation due to a present stimulus. It follows from this, that when we see a rapid motion, we shall not only see a number of positions of the moving body simultaneously, but we shall see them with different degrees of intensity, the present position most vividly, and the others with diminishing vividness, until sensation fades away into immediate memory. This state of things accounts fully for the perception of motion. A motion is *perceived*, not merely *inferred*, when it is sufficiently swift for many positions to be sensible at one time; and the earlier and later parts of one perceived motion are distinguished by the less and greater vividness of the sensations." (*E.W.*, 139–40.)

Discrete stimuli may, therefore, produce continuous sensation Sensations have duration; if stimuli occur faster than the duration of sensations, sensations fuse into each other and produce the perception of motion. This view assumes the discreteness of the world, and is not final, as Russell admits (*E.W.*, 140.) It only shows that the experience of change does not preclude on atomic view of the world. It does not show it to be necessary Even on its own ground, it doesn't represent the whole truth. (1) "In order that the pictures may be animated, there must be movement somewhere. The movement does indeed exist here; it is in the apparatus. It is because the film of the cinematograph unrolls, bringing in turn the different photographs of the scene to continue each other, that each actor of the scene recovers his mobility ; he strings all his successive attitudes on the invisible movement of the film " (Bergson, *Curative Evolution*, p. 322.) (2) Again perception of motion or continuous change implies a *close similarity* between the stimuli ; if lightning is to be experienced as a continuous flash, all its states must have *the same general character*. We do not perceive a continuity between lightning and the rain though they may occur simultaneously. (3) Further, the different staccato strokes of stimuli must occur in some *pattern* or *order*, if our sensations of them are to fuse into one Such pattern or order implies a *unitary source* in the *nature of the stimuli*—lightning implies electric charge ; melody is governed by unity of mood in the musician and so on But it must be admitted that perceptual experience of continuity is but a slender basis for metaphysical identity It can only point to continuity in the experiencing subject , it does not prove it in the experienced objects. It points to the need of the synthetic unity of Apperception. The subject must hold together the successive phases of the object and grasp it as a unity, if there is to be experience of change. But Russell would not admit even this need. He would hold that sensations and images with certain 'mnemic phenomena' are sufficient to account for all activities of the subject. But it is enough to point out that Russell's physiological answer fails to show that stimuli may be discrete, since there must be movement somewhere if they are to produce the illusion of indivisible change. And Bergson's argument doesn't rest merely on perceptual experience of change.

2. The Psychological Proof.

This line of thought is the central interest of Russell. He attempts to bridge the gulf between sense-data and physics. If it is possible to regard the particles, points and instants of physics as constructions from sense-data, there will be a continuous passage from the realities of common sense, sun and moon and stars, etc , to the realities of physics, of electrons and protons. And whatever differences there may be between sense-data and electrons are only appearances due to the character and limitations of the sense organs, and nervous system through which we perceive reality. If sense-data present us with continuous change, it may only be appearance; the real may be a 'compact series' of sense-data, of which we perceive only certain intervening stages within certain limits imposed by the conditions of our organism. In Analysis of Matter, Russell essays this task of showing how physics can be constructed from sense-data. He develops a metaphysic of 'neutral stuff' from which both sense-data and electrons are constructions.

With regard to the argument for continuity of existence from sensory continuity, Russell points out an old but conclusive reason emphasized by Poincaré for believing that sense-data may be, and *must* sometimes be, really different when we cannot perceive any difference between them "In all cases of sense-data capable of gradual change, we may find one sense-datum indistinguishable from another, and that other indistinguishable from a third, while yet the first and the third are quite easily distinguishable" (*E.W.*, 141.) Russell gives the examples of intermediate additions of weight or shades of colour being indistinguishable as showing the possibility of unperceived sense-data. There may be difference, therefore, when identity is perceived "Such considerations as the above show that, although we cannot distinguish sense-data, unless they differ by more than a certain amount, it is perfectly reasonable to suppose that sense-data of a given kind, such as weights or colours really form a 'compact series'." (*E.W.*, 142.)

This is heroic in its logic and worthy of Russell. But surely a *sensation* that is not *sensed* is a contradiction in terms We are not obliged to postulate it at all We have a sensation only when we have it. If we do not perceive the intermediate additions of weight or changes of colour, we need not postulate "little perceptions". The stimuli must attain a certain magnitude and pattern, if they are to be accessible to consciousness. The intermediate stimuli are only physical stimuli, and the mind becomes aware of them only when they pass a certain threshold or limit We can see and hear light and sound waves of only a certain length or amplitude. In this argument, Russell seems to have forgotten the distinction between sensation and sense-data, which he himself makes. "The view that sense-data are mental is derived, no doubt, in part from their physiological subjectivity, but in part also from a failure to distinguish between sense-data and 'sensations'." By a sensation I mean the fact consisting in the subjects' awareness of the sense-datum. Thus a sensation is a complex of which the subject is a constituent and which therefore is mental The sense-datum, on the other hand, stands over against the subject as that external object of which in sensation the subject is aware." (*Mysticism and Logic*, p. 152) He holds that sense-data are physical, and that sensation is psychological consisting of our awareness of sense-data If sense-data are physical, this psychological argument adds nothing to the earlier physiological one of discrete stimuli producing continuity of sensation. If they are psychological, and consist of sensations, there is a perceived gulf between the earlier and the later sensations of weight or colour, and hence they cannot constitute a 'compact series'.

Russell urges the same conclusion by a mathematical interpretation of perceived motion He says that there is nothing in perceived motion which precludes us from regarding it as a 'compact series' He says that the mathematical interpretation is possible, and is consonant with facts We may admit that it is possible within the limits of an assumption of homogeneous quantity, excluding qualitative distinction but we are constrained to point out that it is not consonant with the facts in their integrity "Let us consider a body which is moving swiftly enough for its motion to be perceptible, and long enough for its motion to be not wholly comprised in one sensation Then, in spite of the fact that we see a finite extent of the motion *at one instant*, the extent which we see at one instant *is different* from that which we see at another Thus we are brought back after all to a series of momentary views of the moving body, and this series will be compact, like the former physical series of points" (*E.W.*, 141) (1) The difference is not absolute; there is no complete break between our perception of one momentary state and of another. On the other hand, the difference is *perceived as in the same moving body* The different extents are perceived as parts or phases of the same whole, the extent of one is perceived as merging into the extent of the other. Otherwise there would be *different perceptions of different extents* There would be absolutely no ground for saying that they belonged to the extents of the same moving body. The very idea of a *single moving body* would not have arisen. If it be said that this merging of sensations into each other is no proof of continuity, we are back again at Russell's physiological argument of discrete stimuli causing continuous sensation, and the novelty of this mathematical proof disappears. If Russell sticks to the mathematical interpretation, he cannot account for our experience of motion. (2) In this passage, he says that "we see a finite extent of the motion at one instant." We may ask whether this finite extent perceived at one instant exhibits change, a pattern of before and after? *If it does not*, how can a succession of static states produce an experience of continuous change? If Russell falls back upon the physiological consideration of persistence of sensations and discreteness of stimuli, the psychological argument disappears. In fact, this argument is neither physical nor psychological but mathematical. Only if we grant the mathematical assumption, can sense-data be regarded as 'compact'. (3) Further, Russell speaks in this argument of seeing '*an extent of motion at one instant*'. Does he here mean what he says? Is this instant to be taken in his strict mathematical sense of the dimensionless unit of the cantorian series? Surely in such an instant, no conscious perception can take place Strictly, Russell is committed to view an act of perception enduring through a moment of perceived time as consisting of an *infinite number of little acts of perception* taking place in an infinite number of pure instants. Indeed, Russell draws the implication himself which leads to his view of sense-data as forming a compact series, (considered above) the last absurdity of viewing sensation as consisting of little unsensed sensations.

3. The Logical Proof.

The logical answer of Russell in favour of discreteness is particularly sketchy and offhand He supposes that the Bergsonian and other views that motion is indivisible and is not validly analysable into a series of states, to be part of the doctrine that analysis always falsifies, because the parts of a complex whole are different as combined in that whole from what they would otherwise be. He traces this doctrine to the theory of the internality of relations and reduces it to absurdity by summarizing it in this way.

'There can never be two facts concerning the same thing.' "The doctrine would require that a man who is a father cannot be strictly identical with a man who is a son, because he is modified in one way by the relation of fatherhood, and in another by that of sonship" (*E.W.*)

Now, it is not necessary to suppose that analysis always falsifies with Bergson. Analysis works upon the felt unity of a whole, and never leaves touch with it. It is only emphasis of features, not separation of elements, and emphasis upon a background. It is only one side of the thought-process. The other side, the synthetic, maintains contact with the felt ground , that is why it is possible to regather the threads of analysis into the unitary design displayed in the object

Again, the theory of internal relations does not imply that "There can never be two facts concerning the same thing" It leaves ample room for all differences The man who is a father is strictly identical with the man who is a son, by virtue of his manhood and human individuality But in his relationship as a father he displays modifications which are different from the modifications he displays in his relationship as son His difference as father and son rests upon his essential nature Just as it is open to Russell to postulate multiple relations, it is open to others to postulate 'essential natures,' systems of quality and relation, complex in nature, such that they exhibit different modifications in different relationships The internality of relations neither dissolves the terms, nor necessitates their absolute simplicity

On such hasty grounds, Russell rejects Bergsonian and other objections and asserts the possibility of change as succession of states (*E.W* , 151) His proof consists of a supposed logical necessity If he had said necessity for a particular theory of mathematics, it would have been plausible

"There cannot be change,—and motion is only a particular case of change—unless there is something different at one time from what there is at some other time Change therefore, must involve relations and complexity, and must demand analysis So long as our analysis has only gone as far as other smaller changes it is not complete , if it is to be complete, it must end with terms that are not changes, but are related by a relation of earlier and later In the case of changes which appear continuous, such as motions, it seems to be impossible to find other than change so long as we deal with finite periods of time, however short We are thus driven back, by the logical necessities of the case, to the conception of instants without duration, or at any rate without any duration which even the most delicate instruments can reveal " (*E.W* , 151)

This is a remarkably self-revealing passage It reveals Russell's attitude in all its naiveté It reveals two dogmas

1 Change consists of succession of states
2 These units of change are durationless

With regard to the first assumption, it is necessary to point out that succession of distinct states is not the whole story As Dr Whitehead puts it, "Time is known to us as the succession of our acts of experience, and thence derivatively as the succession of events objectively perceived in those acts. But this succession is not pure succession it is the derivation of state from state, with the later state exhibiting conformity to the antecedent Time in the concrete is the conformation of state to state, the later to the earlier, and the pure succession is an abstraction from the irreversible relationship of settled past to derivative present." (*Symbolism*, p. 41) The successive states are only phases of a passage or event There is continuity of essence or character throughout the phases Russell is led to emphasize the atomic side of reality, partly on account of temperament and partly on account of a fear of 'substance' But to admit continuity of essence or nature is not to admit inert substance. This fear of the Cartesian substance haunts Bergson also, and leads him perilously near denying continuity together with atomic states. But he brings out the aspect neglected by Russell in his accounts of real or concrete duration "For our duration is not merely one instant replacing another, if it were, there would never be anything but present —no prolonging of the past into the actual, no evolution, no concrete duration" (*Creative Evolution*, p. 5) "Duration is the continuous progress of the past which gnaws into the future and swells as it advances" Thus, though there is no string connecting the beads, because the phases are not distinct beads, there is a living unity of past and present, a community of nature between them, which accounts for the conformation of the later to the earlier of which Whitehead speaks, and of the gnawing into the future of which Bergson speaks. There can be no 'conformation' and no 'gnawing' or 'swelling', if there is no unitary nature passing through phases. Both unity and multiplicity are integral elements of change, as of all experience

In this passage, Russell speaks of the logical necessity of pushing analysis to the point of durationless instants for the sake of 'completeness' "So long as our analysis has only gone as far as other smaller changes, it is not complete; if it is to be complete, it must end with terms that are not changes, but are related by a relation of earlier and later" It is natural to ask .—

1 Why should it be complete?

2. What is meant by terms "that are not changes, but are related by a relation of earlier and later"?

1. Why should analysis be complete? What is meant by completion? Russell seems to be more interested in completing the analysis than in the thing analysed. If change is not analysable beyond a point, surely the lesson is that further analysis hangs in the air, and operates on nothing. The hint is given to stop analysis, and accept what is left as the last analysable If Russell goes further and changes the character of motion into an infinity of motionless units, it is in obedience not to the nature of the matter analysed, but to the mathematical theory of infinity. The necessity is not logical but mathematical This distinction between logical and mathematical necessity, of course, does not appeal to Russell, because for him the two are the same, but that is another story.

2. Russell is undismayed by the results of his analysis "terms that are not changes, but are related by a relation of earlier and later." This is to omit content and retain structure. It is a heroic contradiction, an antinomy! How can terms, that are not changes, have a relation of earlier and later? Must we not push analysis further and sunder the 'earlier' from the 'later'? What then is left? Russell takes the mathematical theory of infinity as a literal description of Reality and is landed in this antinomy He considers the antinomies of Kant and the puzzles of Zeno, and solves them by means of the magic of Cantor's theory of infinity

But it is open to question whether that theory itself is free from contradictions if taken as a complete account of reality, and not as a pure mathematical principle of use in the development of mathematics The lesson of Kant's antinomies and Zeno's puzzles is that Time as succession of distinct states is not an adequate category for the description of the Real.

If points and instants have magnitude, a finite space and time cannot contain infinite points and instants.

If points and instants have no magnitude, a finite space and time can contain an infinity of them, but they become logical fictions, and are inapplicable to reality.

Further, points and instants are hypothetical constructions of pure space and pure time. But if space and time are only abstractions from the Real, *i e.*, events, these hypothetical entities also share their abstract character. If the unit of reality is an event particle, points and instants are meaningless by themselves.

"Time is known to me as an abstraction from the passage of events. The fundamental fact which renders this abstraction possible is the passing of nature, its development, its creative advance, and combined with this fact is another characteristic of nature, namely, the extensive relation between events. These two facts, namely, the passage of events and the extension of events over each other, are in my opinion the qualities from which Time and Space originate as abstractions." (Dr. Whitehead, *Concept of Nature*, p 34.)

It is possible to think of pure space and time as infinitely divisible, for they are pure homogeneous emptinesses with no content whatsoever.

The difficulty of admitting infinite divisibility, or an infinite number of points and instants in the Real, lies in the fact that it compels us to regard it as consisting of momentary, perishing states, with no bond of unity between them "In short, the world the mathematician deals with is a world that dies and is reborn at every instant,—the world which Descartes was thinking of when he spoke of continued creation" (Bergson, *C E.*, pp 23–4.) The bond of mathematical continuity of points and instants does not really bind, for it consists of logical fictions—discrete, spaceless and timeless units. Bergson's argument of the impossibility of accounting for motion from juxtaposition of immobilities is not really answered by Russell. Bergson's argument doesn't rest merely upon the nature of perceived time, but on the metaphysical or logical principle that discreteness is not fundamental, but requires a unifying character. Duration is one and indivisible means that each block of duration displays a continuity of content throughout That is why Bergson speaks of the past rolling itself into the present, and the present gnawing into the future.

Russell admits that an infinity of points and instants in finite space and time is neither scientifically nor logically necessary, but only possible. Yet he nowhere analyses the relation between possibility and actuality. Is mere possibility *possible*? Does not possibility require a system of actuality for its ground? Possibility must be shown to be grounded in the Real, before it can be accepted as a live possibility, as a correct account of things.

By temperament and training Russell is an atomist. He wields the instrument of analysis wherever he can and finds an infinity of ultimate elements everywhere. All appearance of continuity, of identity, is only illusory, due to insufficient analysis, or the grossness of our senses This attitude is refined with the mathematical theory of continuity as a 'compact series' of infinite points or instants, and applied bodily to every sphere of existence, sense-data as well as electrons, mind as well as matter Russell is one of the founders of the modern mathematical logic. This atomistic bias of his blinds him to the basis of content,—quantity, number,—whatever it may be called, in the constructions of mathematics and leads him to identify mathematics with logic Atomistic interest leads him to found mathematical logic on pure analysis, on pure principles of logic, in complete abstraction from the Real. But it is a question whether he and his collaborators have succeeded Poincare thinks that they have not, and cannot, on their presuppositions That is why they have to postulate certain axioms or indefinables. "His book (Boole's *Laws of Thought*) was in fact concerned with formal logic, and this is the same thing as mathematics " "We start in pure mathematics, with certain rules of inference, by which we can infer that if one proposition is true, then so is some other proposition These rules of inference constitute the major part of the principles of formal logic. We then take any hypothesis that seems amusing and deduce its consequences If our hypothesis is about *anything*, and not about some one or more particular things, then our deductions constitute mathematics. Thus mathematics may be defined as the subject in which we never know what we are talking about nor whether what we are saying is true "

Now this cannot be strictly true *Any* is not equivalent to *None* We do not apply the rules of inference to any hypothesis that seems amusing, but to that aspect of any hypothesis that lends itself to mathematical treatment. We cannot have a mathematics of meaning, but only of structure

And we do know what we are talking about in mathematics, *i.e.*, the properties of number, or of space. Mathematics cannot be identical with logic. All its formulæ and constructions apply and hold good only on the basis of certain assumed entities, abstracted from the real world—such as magnitude and number. All mathematical development is possible, as Aliotta points out, on account of the *synthesis* of *content implied* in axioms *about space and number*. If Russell insists on purity and formality, he can get only one Law—that of Identity in Difference. All the rules of the syllogism are deducible from it, and the postulates of Induction are only special statements of it. And from the principle of Identity in Difference, from pure logic alone, it is as impossible to develop mathematics as to derive physics or psychology. We cannot ignore the lesson of Kant All knowledge consists of synthetic *a priori* judgments. We cannot drop synthesis, and have pure *a priori* analysis, as Poincare and others point out. The *synthesis may not be human acts* of *synthesis*. *It is the combination of elements in Reality*. The concept of number involves continuity of material, however tenuous, underlying the discreteness Numbers are only prominences in a dim background The concepts of order, class or series also require a homogeneousness of property, underlying their constituents or members, to hold them from straying away into each other. Russell's distinction between pure and applied mathematics is not ultimate "Now the fact is that, though there are indefinables and indemonstrables in every branch of applied mathematics, there are none in pure mathematics, except such as belong to general logic." (*Mysticism and Logic*, p. 75.) The difference between pure mathematics and applied is not that between complete abstraction of all content, and application to special fields, but that between the greatest possible abstraction consistent with a hold on reality,—hold on the quantitative aspects—and special applications to higher levels on the same basis. In physics, it is not 'pure' mathematics of number and quantity, and this application to the material of physics gives rise to new synthesis, fresh developments, not deducible from pure mathematics. And so on in every branch of applied mathematics.

Thus Russell's answer to Bergson fails to constitute a proof of discreteness as adequate to account for duration or real continuity, and his mathematical theory of infinity contains an inner contradiction, and is inapplicable to Reality. It is a question whether his founding of mathematical logic on pure analysis can resist attack.

1. The physiological argument for continuity of sensation from discrete stimuli is not fiinal.

(*a*) It necessitates *qualitative identity* in the stimuli, which has implications dangerous to *ultimate atomicity*.

(*b*) Discrete stimuli can produce experience of continuous change, only if they are governed by *an objective ground* which *determines* the *rapid presentation* of stimuli in a particular *order*.

2. The psychological considerations lead Russell to the absurdity of regarding sense-data as forming 'a compact series' of infinite number of sensations.

This is a confusion of sense-data with sensory awareness.

3. The 'logical' argument rests upon a fancied necessity for completing analysis beyond the point of finite perceptible limits This is not at all necessitated by fact, but by the theory of Cantorian continuity, for which Russell holds a special brief.

4 The mathematical theory itself contains an antinomy, and is inapplicable to Reality. Mathematics cannot be founded upon pure Analysis and formal logic.

Ultimate atomicity is thus unthinkable. Strictly, it would involve utter novelty every instant Russell speaks of causal series How is a causal or any other series possible, if there is no qualitative identity between the members of the series? A haphazard collection of sundry items is not a series. Further, what is meant by causal relations in an absolutely atomic world—of entities, both quantitatively and qualitatively distinct from each other? Not a single formula is possible in such a 'world',—no differential or any other kind of equations. There will be no variables, no functions and no logical or any other kind of constants. All the events constituting the history of an electron must have something in common by virtue of which they *constitute* the electron All the points must have something or somewhat in common, by virtue of which they *are* points, or are *called* points. In a word, the metaphysical argument rests upon the inescapable validity of the Law of Identity in Difference. It is not merely a law of thought; it is the most ultimate law of reality.

TIME AS ULTIMATE.

Bergson is the protagonist of Time. If continuity is perceptual illusion to Russell, it is the essence of reality for Bergson. He maintains the integrity and indivisibility of change If intellectual analysis leads us to discreteness, to atomicity, it is not a suitable instrument for revealing reality

Bergson develops his view in a continuous polemic against mechanism, against static concepts of the real But his descriptions of concrete duration imply and call for a unitary essence persisting in the changing phases, call for another 'dimension of time' which is eternity. "Like radical finalism, although in a vaguer form our philosophy represents the organized world as a harmonious whole" (*Creative Evolution*, p. 53.) "Life, on the contrary, progresses and *endures* in time" (*C E*, 54.) " . . . this reality is undoubtedly creative *i e*, productive of effects in which it expands and transcends its own being" (*C E*, 55.) "Something of the whole, therefore, must abide in the parts; and this common element will be evident to us in some way, perhaps by the presence of identical organs in very different organisms." (*C E*, 57) "For our duration is not merely one instant replacing another; if it were there would never be anything but the present—no prolonging of the past into the actual, no evolution, no concrete duration Duration is the continuous progress of the past which gnaws into the future and which swells as it advances" (*C E*, 4 and 5) These expressions have no meaning if they exclude reference to an essence or material, connecting the several phases, and revealing itself progressively in them. "A harmonious whole", endures in time, expands and transcends its own being, the common element evident in the presence of identical elements, prolonging the past, and gnawing into the future are phrases inexplicable if a central reality taking successive forms is denied.

Bergson proves the identity of impulsion by similarity of organs in divergent channels He is thinking of the whole course of the evolution of life on the planet. But if we think of each organism and its life, we must postulate a central essence, a determinate nature, revealing itself in the changing phases of its growth and decay. It need not have clear models of ready-made ends. It will forge its own purposes in the stress and strain of its life.

Accepting the lesson of relativity, we must think of the life of each organism as a whole. Momentary snapshots will not give us its true nature. Its full nature is revealed throughout the changing phases of its life. If we cannot describe a bit of matter adequately without reference to the time axis, the greater is the need of taking account of time in the case of living organisms But time is not the whole story. The changing phases from birth to death reveal a unity of essence, a '*continuity* of *interpenetration*,' (*C.E*) which is the eternal background. The concrete reality cannot be fully described therefore, in terms of change alone, but needs supplementation by another dimension. The real-in-duration, essence-taking-form is the full nature of the observed fact. This is what Gentile means when he speaks of Mind as Pure Act. Bergson does not draw this implication because he is absorbed in combating mechanism, and mechanistic finalism, and because he is afraid of the Cartesian substance, the string that runs through the necklace of beads "Instead of a flux of fleeting shades merging into each other, it perceives distinct, and so to speak *solid* colours, set side by side like the beads of a necklace, it (*i e*, the mind) must perforce then suppose a thread, also itself solid to hold the beads together." (*C.E*, pp. 4.) .. "As a matter of fact this substratum has no reality, it is merely a symbol intended to recall unceasingly to our consciousness the artificial character of the process by which the attention places clean-cut states side by side, where actually there is a continuity that unfolds" (*C E*, p. 4.) It is a strange meeting of extremes that both Bergson and Russell should inveigh against the same abstraction of substance, that both should feel the necessity of clearing the same lumber before proceeding Instead of a permanent piece of matter, we have now the conception of a "World-line, which is a series of events connected with each other in a certain way' (p 244.) " ..... A light wave is analogous to a material unit; it differs in the fact that it spreads spherically instead of travelling along a linear route." (Russell, *Analysis of Matter*, 246) Both are unconscious that the work was done long ago. The transition from substance to subject, from pre-Kantian thought, both empirical and rational, to post-Kantian thought has not been assimilated in contemporary philosophy. The whole work needs to be done again with special reference to fresh regions of fact, physical and psychological. The alternative to 'Substance' is not 'mere change or pure atomicity'. It is obvious that both Bergson's 'Continuity that unfolds,' and Russell's "series of events connected with each other in a certain way" imply a reality that unfolds, a stuff or material that runs through the series of events There need be no hesitation in granting that there are no distinct beads, no motionless states, and no permanent substances hiding behind the series of events. But we are still left with the changing phases, with duration. To speak of a common impulsion at the beginning of life is insufficient unless it operates in the organisms every moment, and in every divergent channel of life. If it does, the vital essence in each organism reveals itself in its changing phases; it cannot be identical with them. It is 'Compresent' with its whole duration. It is its eternal background. Vital essence taking form, or manifesting itself in successive forms is therefore the concrete fact.

Thus in Bergson time and concerte duration are identified. The aspect of change is stressed so much that it comes perilously near the meaninglessness of mere change. Reacting against the old idea of substance as a static and indifferent entity binding together momentary states into a mechanical whole, Bergson seems to deny all ground of unity in duration. Duration as mere change without something that changes is as much of an abstraction as clock time, an infinitely divisible whole, empty of all events. But in Bergson himself there is a concrete view of time which needs to be freed from its excessive emphasis on mere change as such. Contemporary thought on Time is involved in blind alleys It is caught between the Scylla of mere duration and the Charybdis of a mathematical infinity of pure instants,—between an abstract interpretation of perceptual and conceptual time.

SYNTHESIS OF TIME AND ETERNITY.

A true view of time is impossible without an adequate conception of eternity. A more concrete interpretation of duration will give a clue to a more adequate solution of the problem of time. Time is to be thought of against an eternal background. Of course discussion is bound to suffer from the necessary employment of metaphors. We must first get rid of the spatial conception of eternity as an endless line. The precept 'Take time seriously' has resulted in an one-sided emphasis on mere successiveness. Perhaps Spinoza is a better guide than Alexander in this matter. At least we cannot afford to forget him even on the crest of the elan vital, even in the nisus and churning of Space-Time.

Duration is a flow, certainly, but it cannot be a mere flow. There is something that flows. Bergson is afraid of admitting this aspect of duration, on account of the bogey of the Cartesian 'matter', an inert substance, which might convert his flow into a 'necklace of beads'. But the fear is groundless. Duration is a concrete process which has '*thickness*'. Something *is realizing itself in the process.* It is not hidden behind the outer wall of the process Principle and process are one Reality is life expressing itself. Mere expression is meaningless; mere duration is unthinkable So is mere substance The flower is a block of duration, an event or series of events, in the language of Relativity. The flower or any bit of reality is a set or system of processes in which its nature is expressing itself. Dr Whitehead speaks of "Realization as the becoming of time in the field of extension" (*Science and the Modern World*, p. 159.) The very mention of 'nature' or 'essence' is enough to perturb contemporary thought, because science and philosophy have not been able to get rid of the paralysing influence of the old notion of inert substance. But here is no inert substance, but a living principle, a plain fact of observation. The flower is not a mere process, it has a uniqueness and individuality, which is different from everything else, which it reveals through all its phases. The whole nature of the flower is not found at any one moment of its existence, neither in the bud nor in the glory of its maturity, nor in its fruitful seed. It is a growth, a duration To appreciate the full nature of its reality, therefore, we have to take account of the essence or system of qualities and relations as well as the changing phases which constitute its life. This indwelling principle is found throughout the growth; its fulness is revealed in the complete life of the flower, not at particular stages of its growth. It is 'compresent' to use Dr. Alexander's word for a different meaning, with the whole process. It is its *eternal aspect* If '*before*', *now* and *after* constitute the three dimensions of time, eternity may be said to be its Fourth Dimension, compresent with all the other three dimensions, just as Time is the fourth dimension of space, and 'compresent' in a looser way with its three dimensions This 'compresence' of eternal essence with temporal phases confers value on all the phases, in different degrees, but each unique in its kind Childhood is not mere undeveloped manhood. The child is not a little man, a means to his future. Every stage of life is primarily an end in itself, and only secondarily a means to a later stage. Every phase is a unique realization of an aspect of the eternal essence, which is not 'thin,' but 'thick", not linear, but multiple in possibility. That is why the play of childhood has in its own way a final value. Every stage is to be lived, and not lost in retrospect or expectation. That is why romantic love is an end in itself, and not a mere means to the good of the race. The flower is not a mere instrument for bringing about fruit and seed; it is an end in itself. It reveals a part of the eternal essence Rabindranath Tagore had this truth in mind when in a poem in the 'Gitanjali' he speaks of 'The unseen playmate' pressing the cignet of eternity on many a fleeting moment of careless joy.

The word 'compresence' is to be taken in a specific sense, more intimate than the relation meant by S Alexander. For him, it is primarily spatial in its reference. The earth and sky, floor and table, even mind and its object, are examples of compresence in his meaning. It means the most universal fact of togetherness in the space-time manifold The words *manifestation*, *expression*, *realization* are nearer the intimate relation we are referring to, and indicate more nearly the nature of the relation between eternity and time, essence and successiveness

Another caution is to be borne in mind in thinking of eternity. It is usually taken in its widest stretch of meaning as referring to the universe as a whole, and the topic is plunged at once into the ultimate metaphysical riddles of the relation between Eternity and the time-process, between the absolute and the world-process. Eternity is a concept which must be built up by analysis of experience, like any other. Any premature flight to the peaks of speculation is likely to render the discussion thin and misty We have spoken of eternity freely even with reference to finite patterns of temporal process, such as physical objects. If the concept of eternity is to have a meaning, it must have roots in the realities of perception. And it is just what we find. Every unit-fragment of process implies a fragment of essence, or material as its ground making 'interpenetration' of its phases possible. If the universe is a unity of space-time systems, it is an eternal essence, infinitely rich in depth and variety, perpetually 'passing' into concrete forms, which are space-time systems Each space-time system, each thing or physical object, from the stars to electrons, would then be the individuation or realization of some aspect of the eternal essence in its own pattern, or determinate structure, the essence persisting from the first moment to the last, in and through its successive phases. "The consideration of the general flux of events leads to this analysis into an underlying eternal energy in whose nature there stands an envisagement of the realm of all eternal objects" "the underlying activity as conceived, apart from the fact of realization, has three types of envisagement These are first, the envisagement of eternal objects; secondly, the envisagement of possibilities of value in respect to the synthesis of eternal objects; and lastly, the envisagement of the actual matter of fact which must enter into the total situation which is achievable by the addition of the future." (*Science and the Modern World*, p. 132. Dr Whitehead) That is to say, the universe is eternal-energy taking form, this manifestation involves universals, has intrinsic value, and takes place through 'matter of fact' or stuff or material Indeed, Dr Whitehead is not afraid of referring to substances "as the individuations or modes of Spinoza's one substance" (*Science and the Modern World*, p. 156) His doctrine of the epochal character of time does justice both to the durational and the enduring, the temporal and the eternal aspects of the real "The duration is that which is required for the realization of a pattern in the given event." (*Science and the Modern World*, p. 158.) "Temporalization is realization." (P 159) ' In realization the potentiality becomes actuality But the potential pattern requires a duration; and the duration must be exhibited as an epochal whole, by the realization of this pattern " (P. 159) These statements bring out that—

1 Time is essential for realization.

2 The real is energy taking form.

3 The underlying energy imposes a pattern for duration.

This energy of particular patterns underlies every form or 'block' of temporal process It is continuous and displays structure and form It is pattern and waves, identity and difference. "This doctrine follows from the doctrine of events, and of the nature of enduring objects " (P. 159)

Thus eternity is not a 'high priori' conception to be mentioned only with God or the Absolute In finite objects it exists as the patterned essence, governing the successive waves of its phases. Reality is pattern governing durations, eternity taking forms

Analogies from Art are illuminating in this connection and bring out the necessity of the Fourth Dimension of Time. When the musician creates out of three sounds, not a fourth but a star, it is the Fourth Dimension that breaks through the sounds and shines as a star. Eternity is the Soul of Time. (S Alexander speaks of Time as the mind of space ; it is truer to speak of Eternity as the Soul of Time , for though time is nearer the heart of reality than space, both are after all forms of its realization.) The vision of the musician is 'compresent' in our sense with the whole song from the beginning to the end. The inspiration of the poem exists from the first line to the last. It is an inveterate mechanical habit to look for the meaning of the whole in the parts. To do so is to reduce the poem to its mechanism, its words, and framework. The secret of the poem is to be found, neither in the prosaic analysis of its parts, nor in the Bergsonian intuition of its flux and duration, but in the central meaning, the integral vision of which the whole evolution of the poem, the unified totality of the Poet's rich and many toned experience, is the shape and embodiment. To look for the nature of the flower in particular stages of its growth is to miss the full essence of the flower. (So do we miss the essence of all reality, even matter, it seems, if we omit reference to the time-factor.) It is to look for eternity in mere time. It is to look for God with the microscope. It is to ignore the Fourth Dimension.

The eternal and temporal aspects form a living unity. Both are indispensable. As Dr Whitehead puts it, temporalization is realization Potentiality passing into actuality takes the form of time or successiveness. But successiveness involves also unity of essence. Bergson's analysis brings out the close relationship between spirit or consciousness and time. But he jumps to the conclusion that time therefore constitutes the stuff of reality, is of the essence of it. These are hasty metaphors. A thing may be necessary without *being the central stuff, a thing may be an organic accompaniment without being the essence.* Now time is necessary, and *is organic to reality, but the essence is eternal,* The eternal essence takes the form of time for its realization. This is what is meant by Time being said to be the form of manifestation, the way or manner in which reality expresses itself. "But to the artist who creates a picture by drawing it from the depths of his soul, time is no longer an accessory ; it is not an interval that may be lengthened or shortened without the content being altered. The duration of his work *is part and parcel of his work.* ......Do we foresee what will appear on the canvas? We possess the elements of the problem ; we know in an abstract way how it will be solved, for the portrait will surely *resemble* also the artist ; but the concrete situation brings with it that unforeseeable nothing which is everything in a work of art. And it is this nothing that takes time Nought as matter, it creates itself as form The sprouting and flowering of this form are stretched out on an unshrinkable duration which is one with their essence " (*C.E*) This passage brings out the vital necessity of time for realization. The vision of the artist needs time to take form, and is itself moulded in the process. Time is therefore real, but is not the whole of reality. Bergson attributes the doctrine "Eternity no longer hovers over time as an abstraction; it underlies time as a reality"—to Plato, and finds fault with it as negating time (*C E.*, p. 335.) But on this point it is the ancient philosopher that is nearer the truth. Eternity underlies time To speak of Time "as a moving image of eternity" is not wide of the mark, if time processes are the embodiments of eternal meanings Bergson claims that "there is *more* in a movement than in successive positions attributed to the moving object, *more* in a becoming than in the forms passed through in turn, *more* in the evolution of form than the forms assumed one after another " (*C.E* , p. 333.) This *more* in movement, becoming and evolution of form can come only from the eternity underlying time. It cannot be derived from the mere indivisibility of change, or interpenetration of phases, or continuity of becoming, for these expressions themselves acquire meaning on the postulation of an identical essence underlying them. Time is the form of manifestation. As Royce puts it, Time is the *form of the will*. He stresses the will, because time refers to the 'passage' from potentiality to actuality which involves activity But it is better to say, it is the form of the self manifesting itself, or in non-committal terms, it is the form that energy must take if it is to pass into actuality But the word 'form' is suspect It reminds us of 'formal', and 'formality' is supposed to be identical with nothingness. This meaning is the joint legacy of formal logic and of Kant Formal logic is supposed to deal with mere forms of thought, apart from all reference to meaning. And Kant spoke of Time and Space as subjective forms of Intuition, as the ways in which we, constituted as we are, intuit or perceive reality. But *form may be objective also. Time and Space are forms of the real*, is the amendment of Hegel , Time is real, therefore, to idealism, even to 'Hegelianism'. Time is the necessary form of reality, for it is in the form of successiveness that reality manifests itself. When it is said that time is not ultimate, it is not meant that it is unreal, that it is an illusion. It is only to say that it is not in *successiveness* we are to seek the *ultimate* meaning of things, but in the eternal essence revealing itself in it. Both are necessary, only time is the shape taken by the eternal in realizing itself Time is unreal, only on the definition of real as ultimate essence; it will then be on the same footing with any other finite aspect or level of reality But of course, it is advisable to stop speaking of the unreality of time in any sense To say that time is the form or 'image of eternity' as Plato put it, is to say that Reality *appears* in the form of process; expresses itself in the form of change. Appearance is thus manifestation,—not illusion or *mere appearance.*

We sometimes hear of an Eternal Now The concept is to be carefully described if it is not to mislead. Much of the prejudice against eternity is perhaps due to this conception hastily understood, and imperfectly expounded The Eternal Now is spoken of in connection with the specious present Just as our tempo is small, the amount we can grasp at one moment is very minute indeed, the eternal being is described as envisaging the whole universal flux in one grand specious present For it the past, present and future is revealed at one glance. This conception is unsatisfactory from a number of points of view.

1. It involves a *unilinear* conception of the universal process There is no Eternal Now, but Eternal Nows. Every space-time system has its own duration, its own tempo, its own specious present. There is no one Now in the Universe. We have to construct a Now in view of certain space-time systems in relation to each other This is the lesson of relativity.

2. The Eternal Now *cannot certainly be taken to include the future* Even if there is no absolute simultaneity, things can be said to occur earlier or later than a third, according to the observer's point of view. But there can be no point of view which can *bring the future, the non-existent into view* To interpret the Eternal Now as including the future is a great fallacy. To speak of the Absolute or God as seeing the future is to speak words without meaning, for the absolute is infinite spirit taking form; the process of manifestation is vital. If the absolute is the underlying aspect of forms or things, it is an abstraction apart from the time-process. The eternal does not stand apart from the flux, and view the past, present and future at one glance. The future is the future, unborn

and non-existent. No doubt its potentiality is in the eternal; the past and the present determine it *in its main lines*, but the *concrete form of its realization is unforeseeable.* Bergson's insistence on the unforeseeability of the future has great value "The finished portrait is explained by the features of the model, by the nature of the artist, by the colours spread out on the palette; but even with the knowledge of what explains it, no one, not even the artist, could have foreseen exactly what the portrait would be, for to predict it would have been to produce it before it was produced—an absurd hypothesis which is its own refutation" (*C.E*, p. 7) This holds good even with regard to the relation between the universal spirit and its manifestations. If changes in our personality constitute 'creation of self by self', in the fine phrase of Bergson, so are the activities of the universal One a creation of self by self, and time is essentially needed for both To speak of a Totum Simul, of a glance of the eternal envisaging the past, present, and future is to darken counsel and confuse issues

The eternal is not therefore a great reservoir of things, from which a selection is exhibited in the temporal process. The eternal is an abstraction apart from the concrete process of time The real is essence passing into process The two exist together in organic relationship The eternal is primary as being the ground and source of value, but the time process is necessary for the embodiment of meaning and value The eternal is not a Chinese box from out of which little boxes are taken out now and then The concrete forms and individuals of existence may arise and pass but the underlying essence does not disappear but takes fresh forms. Reality may say with Shelley's Cloud, "I change, but I cannot die". And each form is unique and fresh, unforeseeable and unrepeatable

To look at things sub-specie-eternitætis is not to abolish time from the scheme of things From the eternal standpoint, time does not vanish, but is seen as the bearer of value, as the form of manifestation We see *through the flux of the world* the *pattern of essence taking shapes in it. To see meaning through change, is not to abolish change.* We rise in thought above the mists and detail of particular existence, and observe the harmony and inter-relationship of things. Every thing falls into place. Nothing disappears except our abstractions and illusory first appearances, solidified in the social heritage and medium.

From this point of view, 'the other world' of religion is only the *true view of this world* It is not anywhere else at the bounds of space, or the ends of time. Everything in this world is seen to be a form of the eternal, when understood as it is in the texture of reality, and not as clouded by what Spinoza calls the Imagination. When we put our obtrusive self aside, and grasp things as they are, in their own relationship, when the mind reflects reality faithfully, we have true wisdom, and see eternity here and now. We see the eternal meaning in the system of forms and existences which constitute the universe. Of course, such a view requires strenuous self-discipline whether in the moral or the scientific sphere—the discipline of the larger self, or the discipline of fact, 'of irreducible and stubborn facts,' in the fine phrase of W James. This discipline involves holding the changing phases of the world at arm's length even while scanning them carefully. But it is not to regard change and time as unreal. It is to endeavour to pierce through them to their meaning. As Professor Radhakrishnan puts it "we must step aside from the procession, if we would see the whole of it." (The Rôle of Philosophy in the History of Civilization. *International Congress of Philosophy*, 1926, U S.A) This stepping aside is not to discard the procession as of no value, it is a means to a fuller vision of it, a closer apprehension of it. All thought involves the rhythmic processes of analysis and synthesis. We must rise above the data, survey it as a whole, analyse it into its elements and relationship, before our knowledge is rendered clear, definite and rich in meaning. But the analytic phase operates on the ground of synthetic apprehension, and the threads of analysed elements are regathered into the synthetic construction at the end. It is only for this purpose that we must free ourselves from the changing aspects of the world, its scintillating and alluring appearances, while retaining our scrutiny of it. This is all that is meant in idealistic thought, when the precept "Rise above the illusion of time" is given We rise above time to see its own true character as the bearer of eternity. The precept "Take time seriously" need not be supposed to clash, therefore, with the precept "Take eternity seriously". To take Reality seriously is to take both time and eternity seriously. We must listen both to Spinoza and Alexander.

This view of the concrete nature of duration as implying eternity derives support from the principle of Relativity. For according to this view we do not neglect the *time* of the *event.* We do not regard the physical object such as the flower, as a 'thing' complete at every stage, each stage indifferent to the other, merely occupying a certain position in three-dimensional space. We regard it as an event, a process to which time is essential. ". The three-dimensional world is obsolete and must be replaced by the four-dimensional space-time with non-Euclidean properties." (Eddington, *Space, Time, Gravitation,* p 181) Thus time is organic to the 'stuff' of things Reality takes the form of process. The space it occupies, and the time it fills are not, as in the Newtonian scheme indifferent to its 'matter' We have exorcised the three ghosts of an empty space, an absolute uniform time, and an inert substance For if time is organic to matter, there are as many times as there are systems of change. The 'mass' of any bit of matter is not, therefore, to be regarded as explicable 'in its own terms', as absolute. The yard stick is not the same everywhere It depends upon the motion of the system which it shares Mass becomes a function of the whole system. It has no inert permanent Core persisting unchanged in all systems of reference. Into the innermost heart of the physical entity, the so-called matter enters the shadow of relativity The thing is what it is, its 'mass' is what it is, because of its position in a system. As Einstein points out the old Newtonian Scheme is built on two assumptions · "In the first place, it was assumed that one can move an ideal rigid body in an arbitrary manner. In the second place, it is assumed that the behaviour of ideal rigid bodies towards orientation is independent of the material of the bodies and their changes of position, in the sense that if two intervals can once be brought into coincidence, they can always and everywhere be brought into coincidence " (A Einstein, *The Meaning of Relativity,* p 5, 1922) Dr Whitehead sums up these two assumptions as constituting the *fallacy of simple location.* Both these assumptions have broken down. There are *no* ideal rigid bodies, and their behaviour towards orientation is *not* independent of their material, and of their changes of position Two consequences emerge from this new view ·

1. Time *matters to* things, passage is an essential characteristic of things, of even 'dead matter' It renders intelligible the idealist's insistence that Time is the *form* of manifestation, that process is necessary to realization.

2. There is no one time, but many times, as many times as there are relatively isolable systems in reality.

Both are familiar in Idealistic thought. Time is an abstraction from reality, as Whitehead puts it. But an abstraction is not an *illusion* It expresses a *real aspect* of the universe. It is integral to it

And the second point is a welcome support to an old thought familiar in Plato, Plotinus, Spinoza, Hegel and Bradley, not to speak of Indian philosophy. The view of the event as concrete duration implies a close union of material with space and time The unit of reality becomes an event, a unity of particle-point-instant Each event becomes a space-time system. The uniform Space-Time framework, a single system throughout the universe disappears, and we are left with an infinity of events, each with its own space-time, or rather each realizing itself, or passing, Space and Time being abstractions from this its passage or creative advance, in the words of Whitehead This means philosophically the abandonment of what may be called a *unilinear conception* of Reality, of Eternity as Endless Line We cannot, therefore, speak of the whole universe being in time Rather we shall have to think of infinite events each with its own space and process, The universe, then "has no histories of its own, though it contains histories beyond number"; (F H. Bradley, *Appearance and Reality*, p 499.) "has no seasons, but all at once bears its leaves, fruits and blossoms. ' The universe cannot, therefore, be said to be in time but in all the space-time events, which together is the world This view answers the question—what happens to the world, when the world-process comes to an end? If we regard Time as necessary to Reality, we have to regard it as endlessness If there is an end, time cannot be real; if there is no end, ideals are unrealizable and so devoid of motive power. This is an antinomy born of abstractions. There is no *one end*. There are ends and beginnings simultaneously. Professor Radhakrishnan postulates another drama in another stage after the world process comes to an end. (The Doctrine of Maya, *International Congress of Philosophy*, 1926, U.S.A) The postulate is unnecessary There is no one drama, no one stage. There are innumerable settings all the time. Infinity has 'breadth', as well as length "The point is, it seems to us, that its evolution and self-revelation need not proceed by any one of what are called progresses or advances,—An infinite whole, it seems to us, must live out alike to all its sides and aspects, must expand into and live itself out in all values" .... "We are rather forced to conceive the whole as a unity which in its infinite life, without narrowing itself to a single time of advance selected from among all the characters of which its life is capable, rather reveals itself through infinitely diversified resources as in all directions an inexhaustible fountain of values." (Bosanquet, *Meetings of Extremes in Contemporary Philosophy*, p. 183.)

This resolves the old Kantian antinomy of a world without a beginning in time. The antinomy disappears if there is *no time* apart from the *events*, no empty plenum, or *container*, existing before the creation of the world. Time comes into existence *with* the world, and as an aspect within it. It has no meaning before it or after it The antinomy becomes self-contradictory if Time is regarded in itself, torn out of its context as a character of the Real. This is the real lesson of the Antinomy All categories or partial features of the world become self-contradictory, when regarded as ultimate, or as adequate to express the full nature of the real This is the meaning of the devastating dialectic of Bradley in the earlier part of his Appearance and Reality Thing, Quality and Relation, Space and Time become self-contradictory when regarded as Real, *i e*, ultimately real, or sufficient to characterize Reality as a whole They all express real aspects integral to things ; only they must not be applied to the whole, and if Reality is defined as The Whole, obviously, they can only be unreal Much of the antagonism to Bradley is due to misunderstanding of his definition of Reality as *ultimate Reality*.

This view of the relation between Eternity and Time also answers the old question of what God was doing before creation, and why he suddenly bethought himself of launching this 'sorry scheme of things' on its fateful career Why should the Absolute consent to be tainted with the descent into this world ? This question disappears if there is no one *Time* pre-existing before the universe. What we have is a universe realizing itself in an infinity of space-times The underlying source expressing itself we call Eternity, the process of expression we call Time They are integral to each other. God does not exist prior to and unrelated to the world There was no Time, when the Absolute was unmanifested. The transcendence of God means, not the pre-existence of God, separate from the world, but the infinite richness or inexhaustible depth which is more than any one or all of the 'histories' taking place, of the space-time systems, or 'epochal wholes' in the language of Whitehead. Infinite essence taking infinite forms is the picture of reality we get if we draw out the implication of the principle of Relativity The unity of all these 'nama rupas,' 'names and forms,' is neither spatial nor temporal, *pace* S Alexander but Eternal. It is a unity underlying Spaces and Times and irradiating them. Eternity is the Fourth Dimension of Time.

There is a further implication of the principle of Relativity with regard to what may be called this 'bipolar' nature of things A thing is what it is in virtue of its own essence and also in virtue of some influence which it shares from the essence of all other things That is why we cannot explain a physical object in terms of its own time and space , in fact, it has no 'time' of its own. We have to construct its 'time' in relation to other systems of reference. It has some *nature* or *being* which lends itself to interpretation in terms of space and time, when considered in relation to other systems of reference. This is the doctrine of the 'Interval,' which is time-like, and space-like The unity of the being itself need not be, indeed, cannot be, supposed to be in space and time. And this unity behind the 'Interval' is "*bipolar*," in nature,—an individual essence bearing a universal influence of some kind or other. This is the 'theory of aspects' in terms of which Dr Whitehead defines the physical entities in the light of recent physics "An event is the grasping into unity of a pattern of aspects." (Whitehead, *Science and the Modern World*, p. 149) "Thus the life of a material particle is its adventure amid a track of event-particles strung out as a continuous series or path in the four dimensional space-time manifold " (*Concept of Nature*, p 180) On page 152, in Concept of Nature, Whitehead speaks of all nature being required for the 'ingression' of blue into the events of nature. All nature is required for the 'experience of blue' or for any event. All nature outside the active conditioning events in any particular experience or events, is involved as 'passive conditioning events' And a "Scientific object such as a definite electron is a systematic correlation of the characters of all events throughout all Nature " The outcome for philosophy of this 'Concept of Nature,' as determined by Relativity, is an 'organic theory of Nature,' in the words of Whitehead himself (*Science and the Modern World*, p. 149)

Russell holds that this theory is not logically implied in the facts of Science, on a mistaken identification of this view with a theory of the 'thing' with 'aspects,' built on the analogy of the old notion of substance. "I conclude, therefore, that the 'thing' with 'aspects' is as useless as permanent substance, and represents an inference which is as unwarrantable as unnecessary " (*Analysis of Matter*, p 248) If the principle of relativity necessitates the taking into account 'all nature,' all 'systems of reference' to describe adequately a particular system of events, it is obvious, the organic view of nature and the theory of aspects set forth by Dr. Whitehead is a straightforward rendering of the facts, not only 'warranted,' but also 'necessary' The lesson is clear that no event can be completely explained in terms of itself. Every event has an aspect which registers or 'mirrors' the rest of the entire universe Each event is what it is, not only because of its own individuality, but of some character in which the rest of the universe is contained 'ideally,' as it were That is to say, nothing is merely individual, but also has a universal aspect. In the heart of the physical event itself is thus discerned a bipolar 'nature,' individual and universal. The universality of each event does not interfere or diminish its individuality. On the contrary, it maintains it. In a way, the thing is the meeting point of relations. The essence or principle of each event is two-fold, individual and universal Thus the Fourth Dimension of each event or series of events, their eternal aspect, has a double nature,—an individuality 'informed' or charged by universal significance. There is a meaning therefore in saying that Time is in Eternity, or is the process of its revelation, not merely in the sense of the individual principle of Duration in each event or system of events, but also in the sense of a universal meaning which it shares

Thus the principle of Relativity leads to the organic Concept of Nature, and the bipolar' concept of the event It renders time vital to the physical scheme, while permitting an eternal aspect in all things. Another growing point of physics in the *region of the 'stuff' of* things itself, is developing theories which bear out remarkably the same conclusion. The "Quantum Theory" supports the conclusions drawn from the relativity of space and time Just as the theory of relativity renders impossible the fallacy of simple location, and lays bare the organic view of nature, the quantum theories seem to point to the breakdown of Atomism as principle of explanation If space and time do not belong to particular systems of reference absolutely, neither is it possible, it would seem, to isolate the ultimate unit of matter of energy, and treat it as a self-contained entity. "The physical world is not to be analysed into isolated particles of matter or electricity with featureless interspace. We have to attribute as much character to the interspace as to the particles, and in present-day physics, quite an army of symbols is required to describe what is going on in the interspace We postulate ether to bear the characters of the interspace, as we postulate matter or electricity to bear the characters of the particles" (Eddington, *The Nature of the Physical World*, p. 31.) The lesson seems clear that *atomicity* cannot be the *ultimate characteristic* of the physical world. If interspace is as necessary as particles, there can be no gulf between them The two are continuous in nature. And even in the light of Clerk Maxwell's equations, it would seem that the atomic unit of matter can be calcuated only in terms of a field of force Matter may not, therefore, consist of isolable particles floating in an indifferent ether. What we take to be particles may only be temporary *foci* in *a continuous medium*, centres or whirls in an all-embracing field. Indeed, Russell considers De Broglie's "new wave theory of Matter," in which "the material point is conceived as a singularity in a wave" (*Analysis of Matter*, p 46) It is inconceivable, how Russell can interpret such a singularity in a wave in terms of his own atomic outlook He continues to speak unconcernedly of *series of waves or radiations* in which matter consists. He goes on to consider Heisenberg's theory and puts the matter in a nutshell If we are to retain the corpuscular theory, we can only do it by not assigning a definite point of space at each time to the electron or atom We substitute a well-defined group of quantities which represent what *was* the place of the electron They are the observable radiation quantities, each of which is associated with two "terms, so that we obtain a matrix" Structure, Rhythm, and Matrix to which Russell is again and again led in his Analysis of Matter is a far cry from his stubbornly maintained atomistic point of view. A *matrix* is certainly an *identity in difference* if ever there is one A *matrix* involves *interrelation of particles*, and their 'bipolar' nature We are back again at the view to which we were led by Relativity, this time in the heart of the 'world-stuff' itself, not merely in its forms of manifestation. The corpuscle, it seems, is not a constant, self-contained entity, the same in all relations, maintaining itself at the same point of space, with an incommunicable essence, untouched by the surrounding matrix or field of force For "it is moreover impossible in principle to identify again a particular corpuscle among a series of corpuscles" (Russell, *Analysis of Matter*, p. 45.) The wave has gone, and is succeeded by others. "Thus if we come across Schrodinger waves uniformly filling a vessel, the interpretation is not that the vessel is filled with matter of uniform density, but that it contains one particle which is equally likely to be everywhere" (Eddington, *The Nature of the Physical World*, p. 214.) Two consequences seem to be indicated.

1 There are no corpuscles eternally the same, with their own incommunicable essence

2 The *potentiality* of these corpuscles *seems to pervade the field of influence* which must have a determinate *nature* which determines its location and its possibility

"What precisely is the entity which we suppose to be oscillating when we speak [illegible] the waves in the sub-ether? It is denoted by (Psi), and, properly speaking, we should regard it as an elementary indefinable of the wave-theory.. . . But the (Psi)—waves of the hydrogen atom are spread about all over the atom and there is no definite localization of the electron, though some places are more probable than others." (Eddington, *The Nature of the Physical World*, p 216)

These developments, therefore, threaten to invalidate the assumption of corpuscles or ultimate units of matter "In seeking to make the position of the particle more definite by reducing the area, we make its energy more vague by dispersing the frequencies of the waves So our particle can never have simultaneously a perfectly definite position and a perfectly definite energy; it has always a vagueness of one kind or other unbefitting a classical particle" (P 218.) Eddington draws the lesson that the classical particle is an untenable assumption born of analogy with gross particles, by means of which we are "misled into untenable ideas of the attitudes of the microscopic elements of world-structure" As absolute time and space units are impossible, so are absolute entities of world-stuff. Therefore both relativity and the development of recent quantum theories of matter militate against *ultimate atomicity as a final category* The real is therefore One differentiating itself into Many in the ancient language of philosophy. The eternal shines through temporal forms. The stress of the waves gives rise to passing singularities. The particle is the concentrated essence of the waves It bears the impress of infinity upon it. Here we are back again at the theory of aspects, developed by Whitehead. The

particle has *aspects* in which are registered the influences of the rest of the universe. The electron in the body is different from the electron outside it In fact, the electron doesn't persist in its own nature and form and essence. It passes, like the wave, and others take its place It is a *temporary individuality* The element of stability in it is the interspace of which it is a concentration, just as the element of stability in us is the universal nature of which we are the embodiments.

Thus recent physics illuminates classical metaphysic and lays bare the essentially abstract character of the mathematical view of time as infinite discreteness If each unitary event bears the impress of infinity upon it, it becomes rather meaningless to speak of point-instants as if they existed by themselves, without any enduring ground. Of course, they are entirely valid within the scientific sphere, and their applicability to the real world shows only that it represents a *genuine aspect* of Reality, the *aspect of structure* As Vaihinger puts it, the mathematical view is an *instrument dealing with the world, not a picture of it* The ultimate nature of reality is not-prejudged by it The universe, therefore, is a unitary fountain of energy, giving rise to infinitely diversified events, each process exhibiting time and space. Each event is at once individual and universal, a particular 'nama rupa' or name and form The universe is a unity of space-times The Real is the Eternal revealing itself in infinite times. Time and Eternity are aspects of reality To take time seriously is therefore to take eternity seriously. A unified concept of both resolves the antinomies of abstract time, and gives the clue to the nature of reality.

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